Biology of the Cell

Understanding the Cell

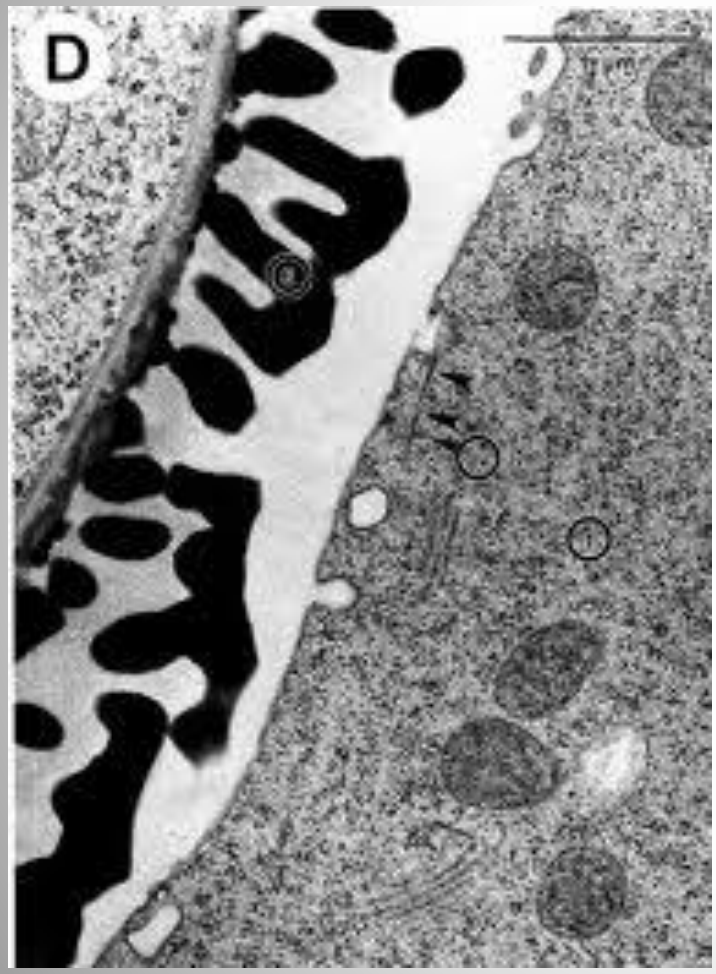
- All body processes dependent upon cells for their activities
- Cells known as “the functional units of the body”
- Knowledge of cell structure and function crucial for understanding anatomy and physiology

Introduction to Cells: How Cells Are Studied

- Cells
  - Studied through the discipline of **cytology**
  - Discovered after the invention of microscopes
  - Measured in micrometers (1/10,000 cm)
- Microscopy
  - The use of a microscope to view small-scale structures
  - Accomplished through staining techniques to provide contrast

Microscopy

TEM vs. SEM



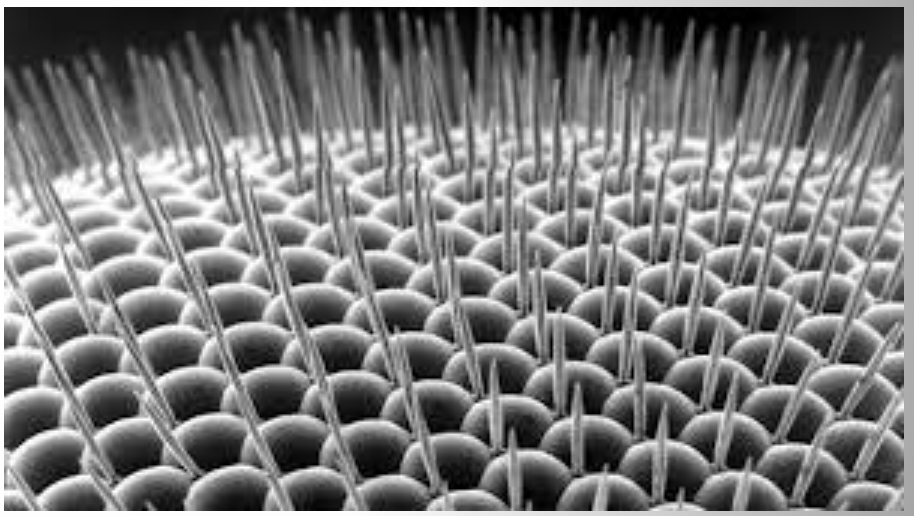
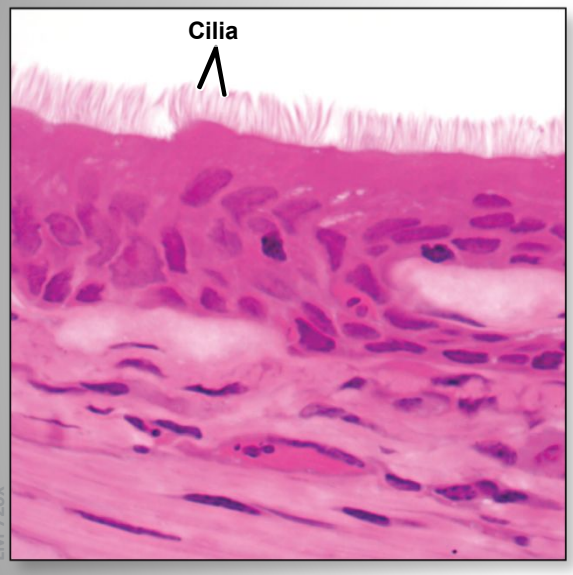
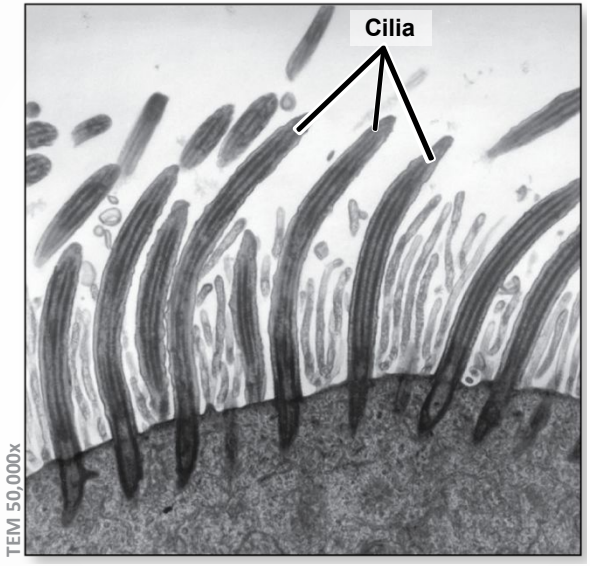


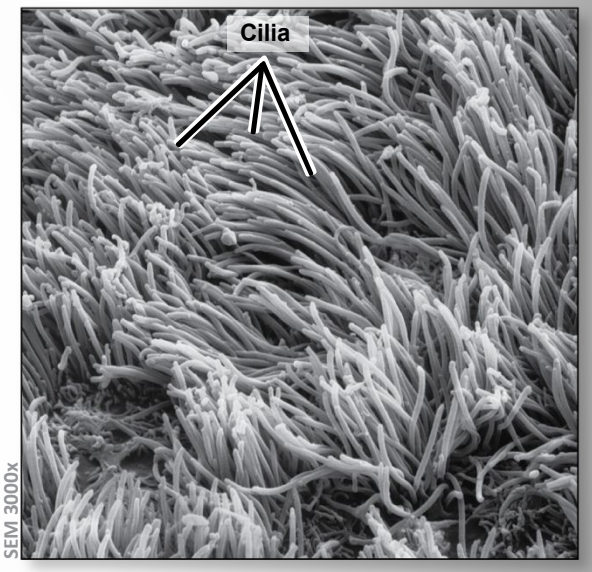
Figure 4.1



(a) Light microscopy



(b) Transmission electron microscopy



(c) Scanning electron microscopy

a: © The McGraw-Hill Companies, Inc./Al Telser, photographer; b: © VVG/SPL/Photo Researchers, Inc.
c: © Eye of Science/Photo Researchers, Inc.

Introduction to Cells: Cell Size and Shape

- Cells vary greatly in size and shape
  - E.g., an erythrocyte between 7-8 nm
  - E.g., an oocyte of 120 nm
  - Most microscopic
  - Shapes spherical, cubelike, columnlike, cylindrical, disc-shaped, or irregular

Figure 4.2

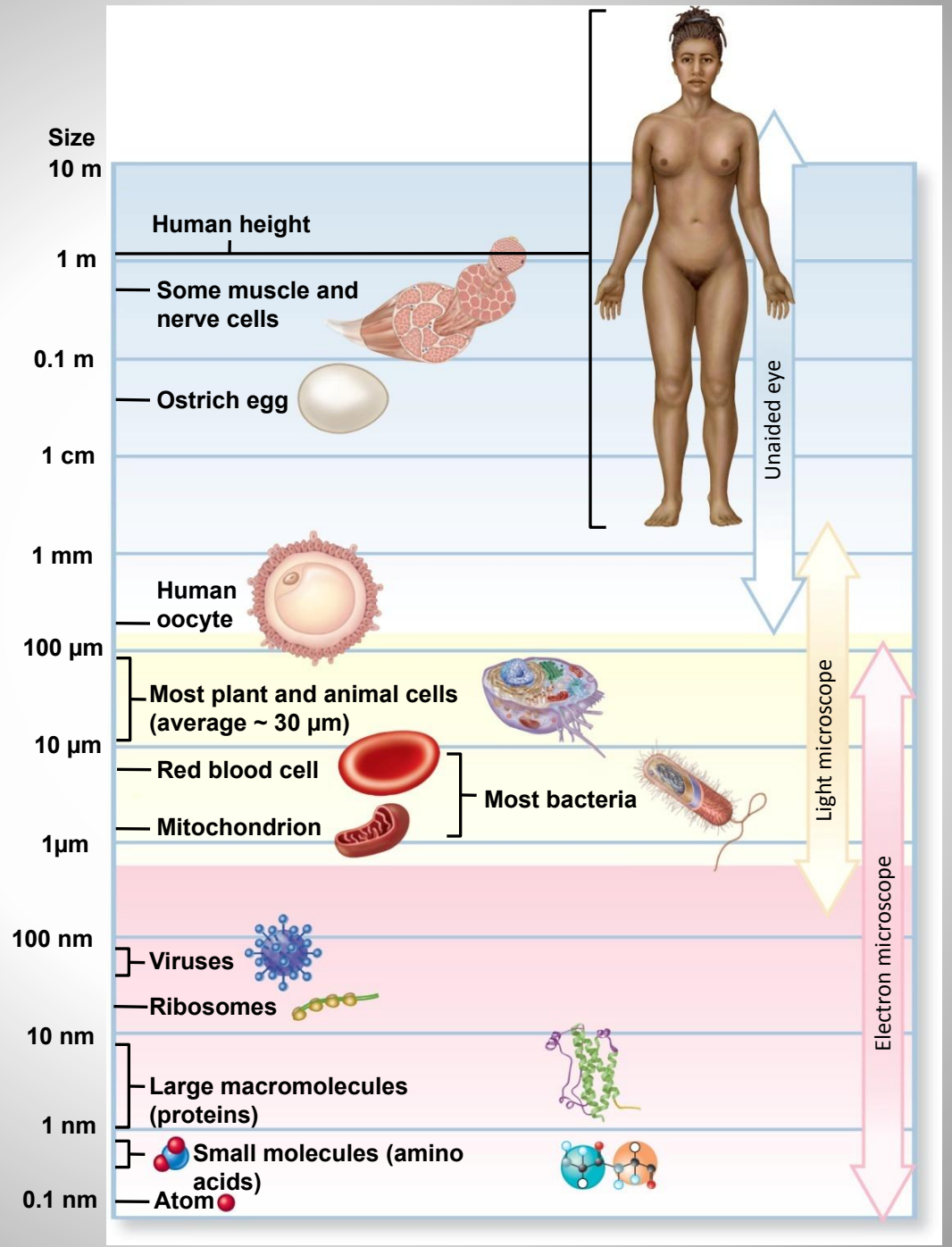
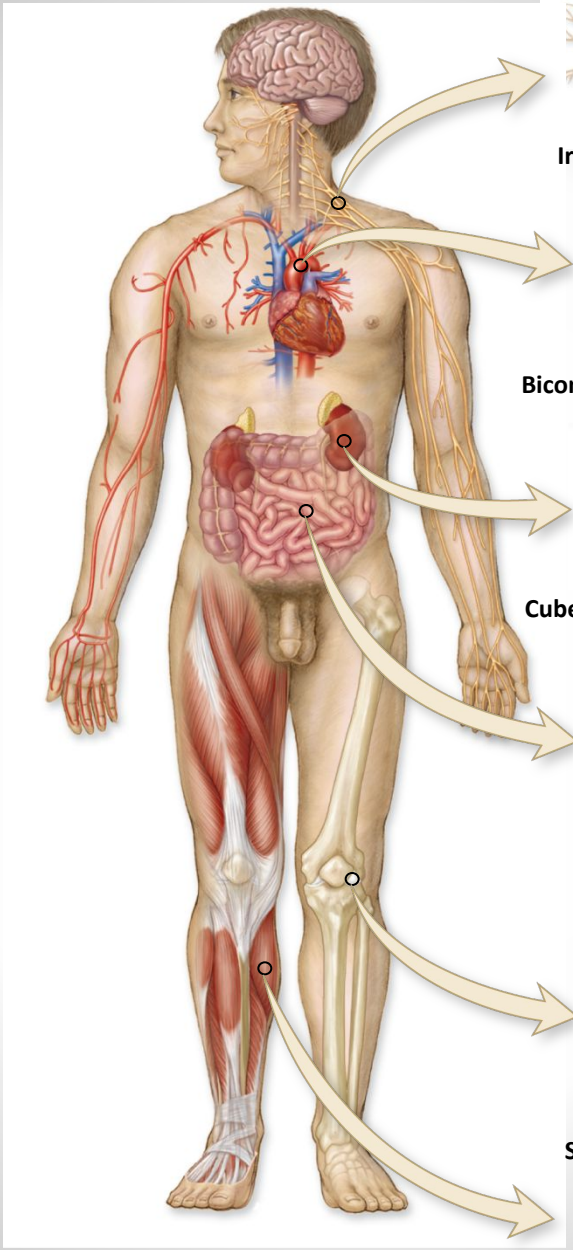
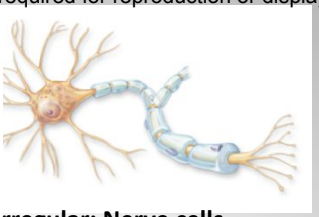


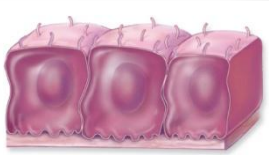
Figure 4.3



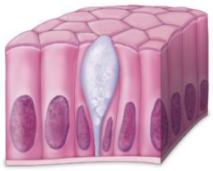


Irregular: Nerve cells

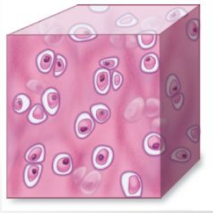
Biconcave disc: Red blood cells



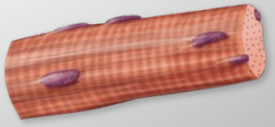
Cube-shaped: Kidney tubule cells



Column-shaped: Intestinal lining cells



Spherical: Cartilage cells



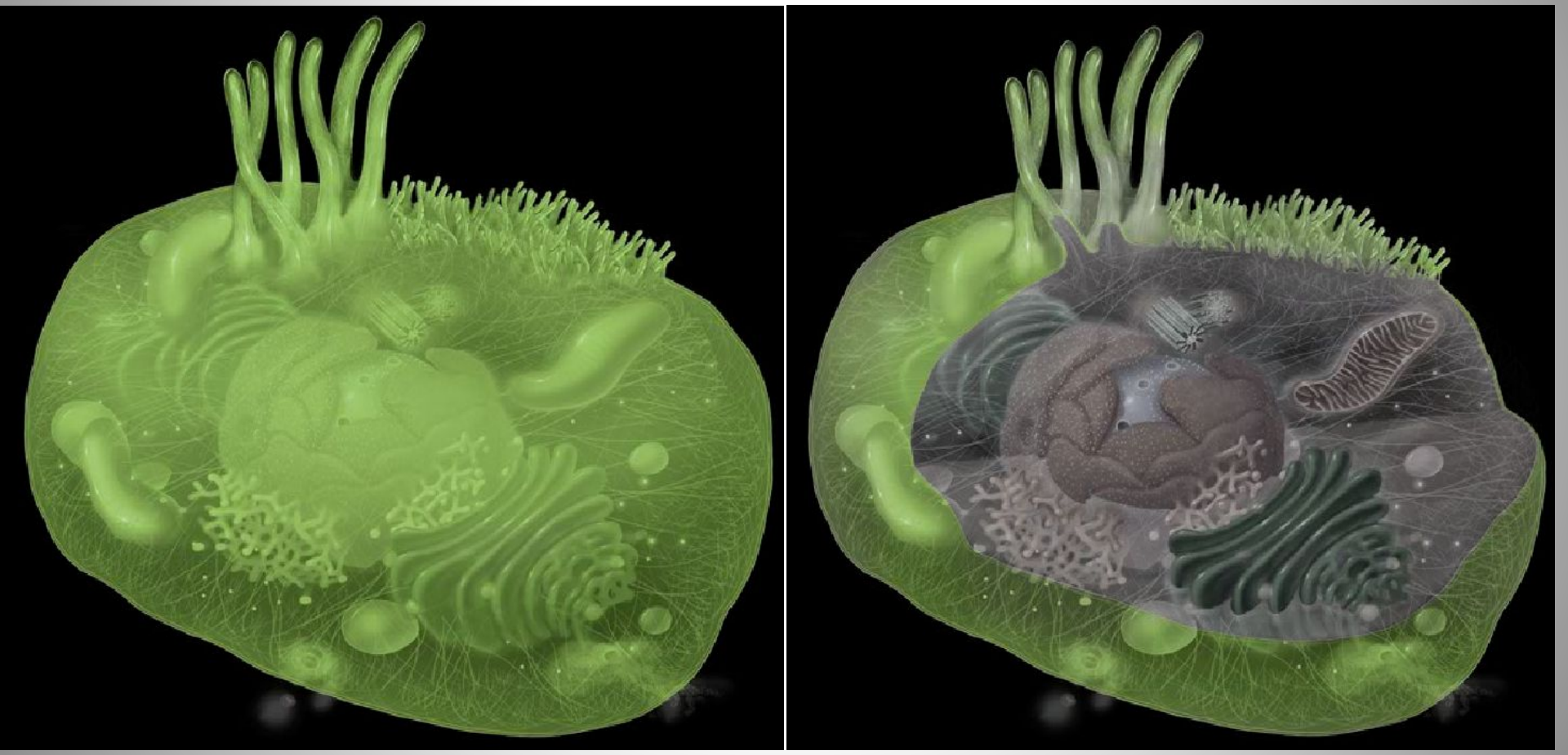
Cylindrical: Skeletal muscle cells

Introduction to Cells: Common Features and General Functions

Overview of Cellular Components

- **Plasma membrane**
  - Forms the outer limiting barrier
  - Separates internal contents of cell from external environment
  - Cilia, flagellum, microvilli
    - modified extension of plasma membrane

Plasma Membrane

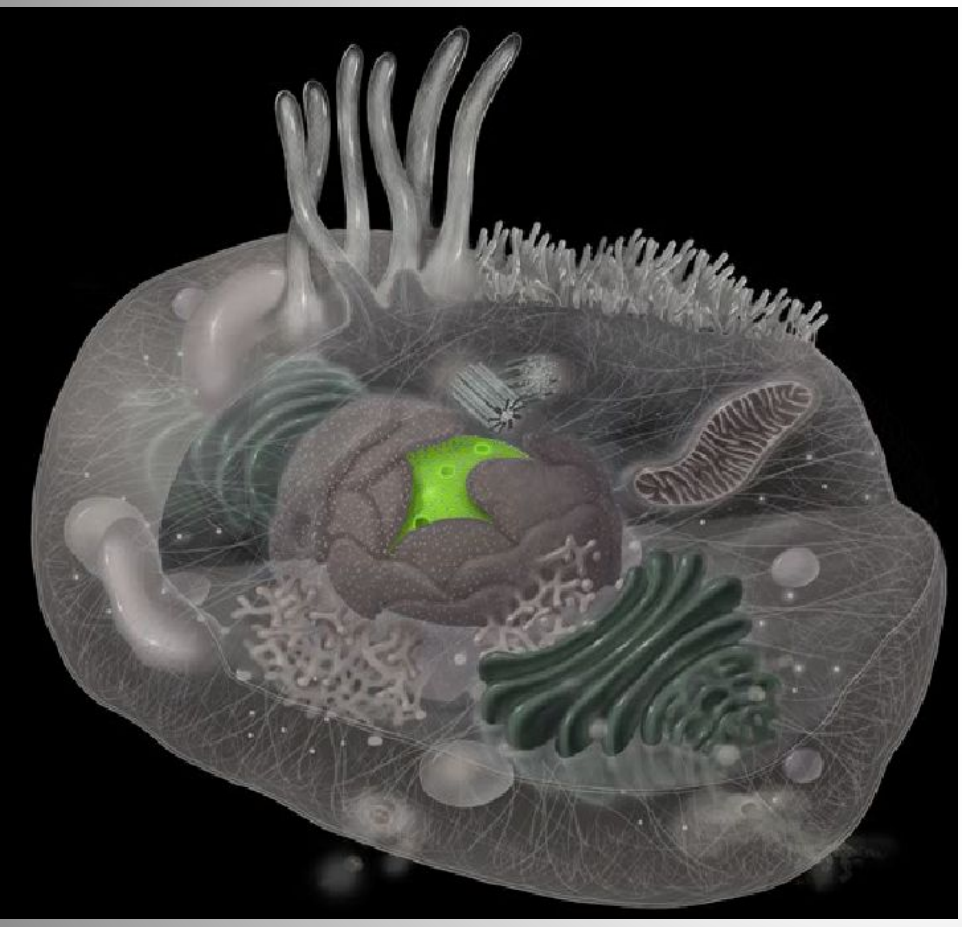


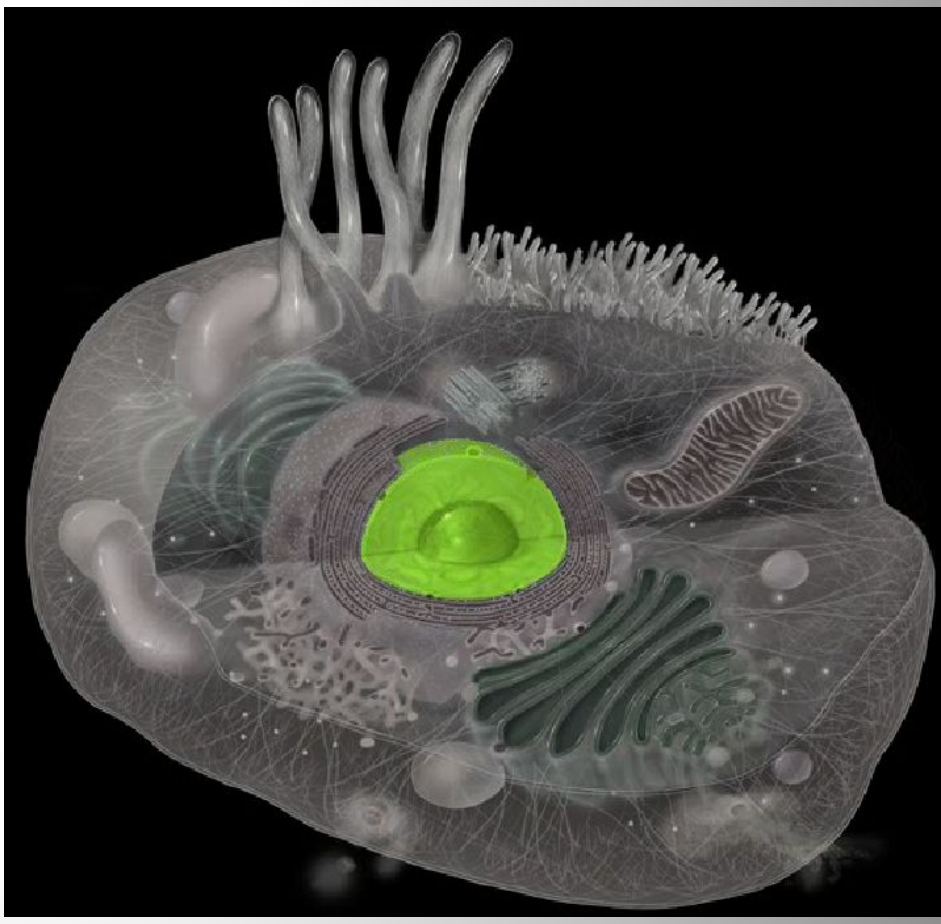
Introduction to Cells: Common Features and General Functions

Overview of Cellular Components *(continued)*

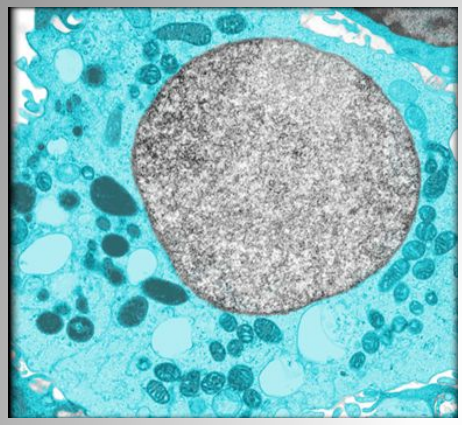
- **Nucleus**
  - Largest structure in the cell
  - Enclosed by a nuclear envelope
  - Contains the genetic material, DNA
  - Inner fluid called nucleoplasm
- **Cytoplasm**
  - Cellular contents between plasma membrane and the nucleus
  - Includes cytosol, organelles, and inclusions

Nucleus

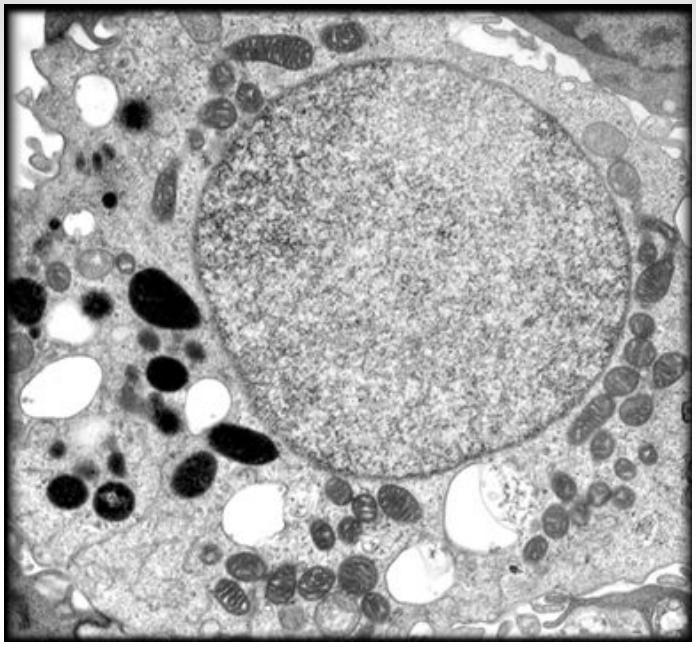


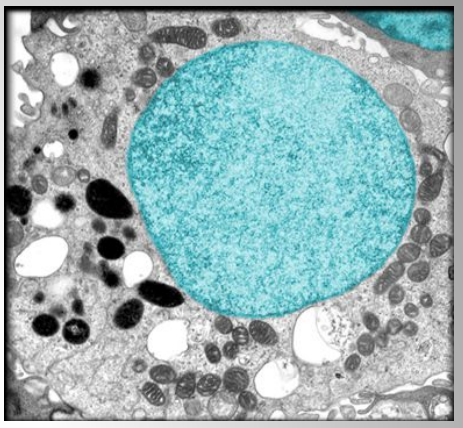


Cytoplasm

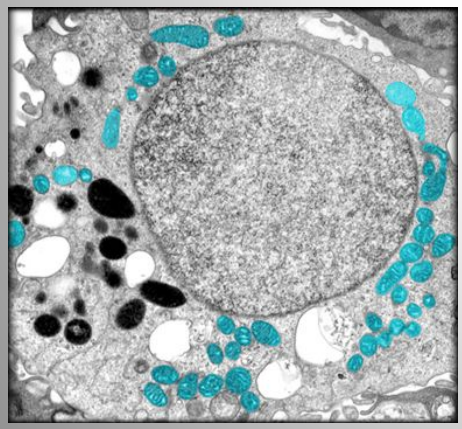


Cytoplasm

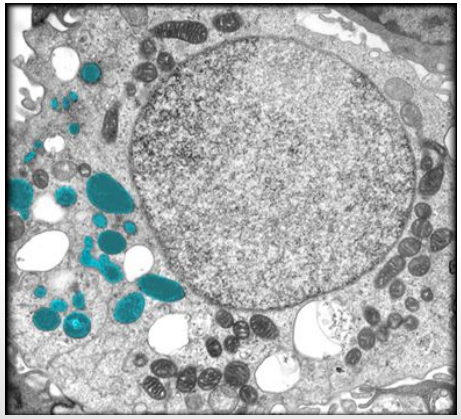




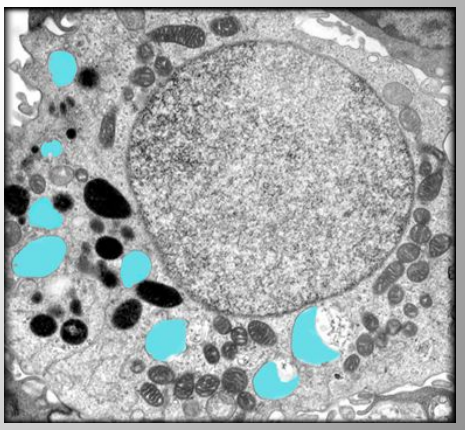
Nucleus



Mitochondria



Peroxisomes



Vesicles

Introduction to Cells: Common Features and General Functions

Cytoplasmic Components

- **Cytosol** *(intracellular fluid)*
  - Viscous fluid of the cytoplasm
  - High water content
  - Contains dissolved macromolecules and ions

Introduction to Cells: Common Features and General Functions

Cytoplasmic Components *(continued)*

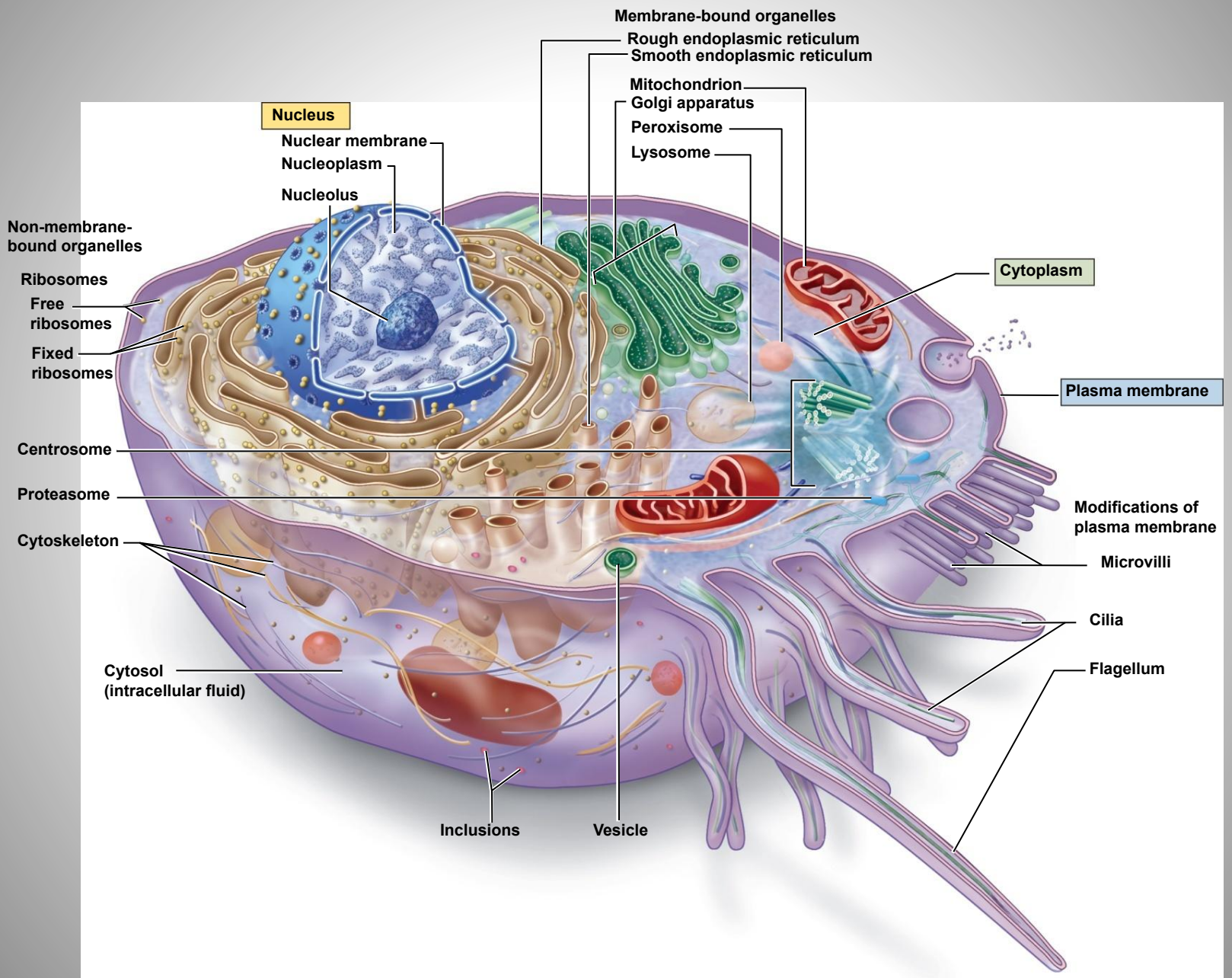
- **Organelles**
  - Organized structures within cells
  - "Little organs"
  - Unique shape and function
  - **Membrane-bound** organelles
    - enclosed by a membrane
    - separates contents from the cytosol
    - e.g., endoplasmic reticulum, Golgi apparatus, lysosomes, peroxisomes, mitochondria

Introduction to Cells: Common Features and General Functions

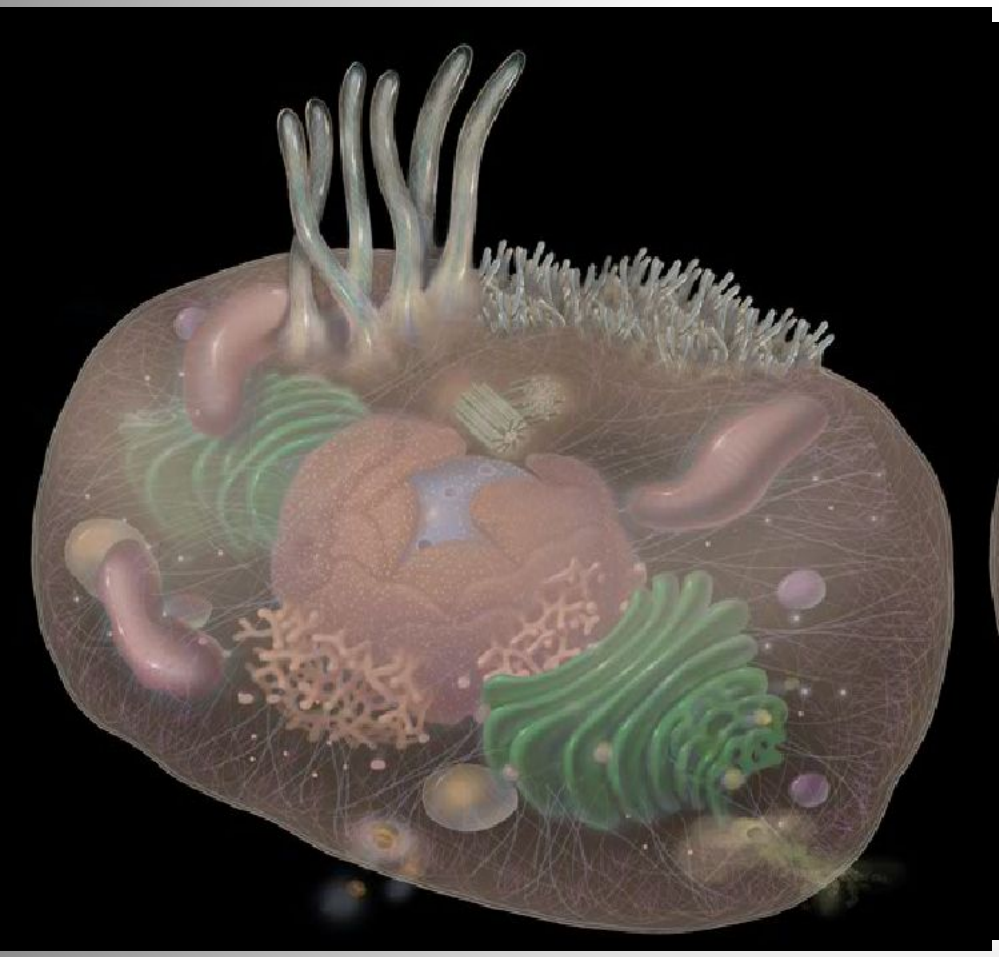
Cytoplasmic Components

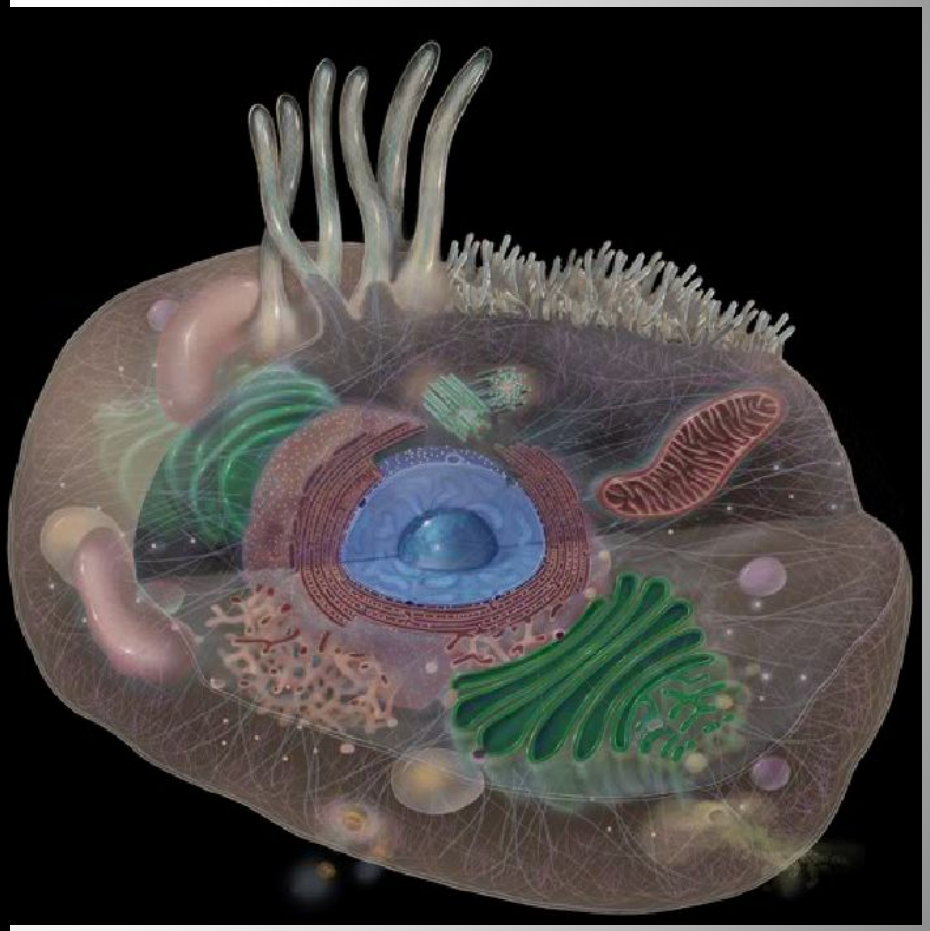
- **Organelles** *(continued)*
  - **Non-membrane-bound organelles**
    - not enclosed within a membrane
    - generally composed of protein
    - e.g., ribosomes, cytoskeleton, centrosome, proteasomes
- **Inclusions**
  - Large diverse group of molecules
    - not bound by membrane
    - not considered organelles
    - e.g., pigments, glycogen, triglycerides

Figure 4.4



The Structure of a Cell





Introduction to Cells: Common Features and General Functions

General Cell Functions

- Performed by most cells
  - Maintain integrity and shape of cell
    - dependent on plasma membrane and internal contents
  - Obtain nutrients and form chemical building blocks
    - harvest energy for survival
  - Dispose of wastes
    - avoid accumulation disrupting cellular activities

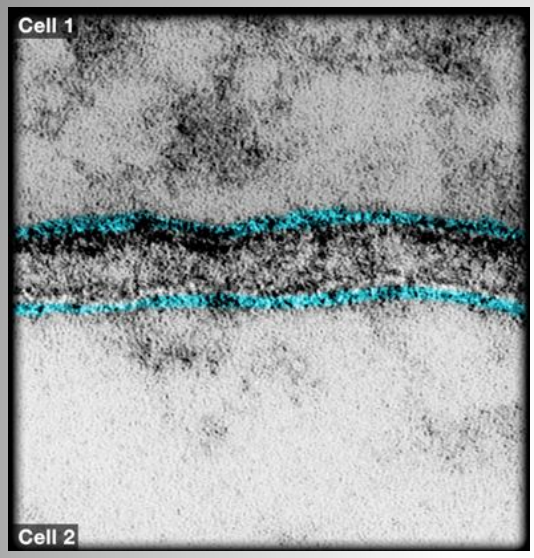
Introduction to Cells: Common Features and General Functions

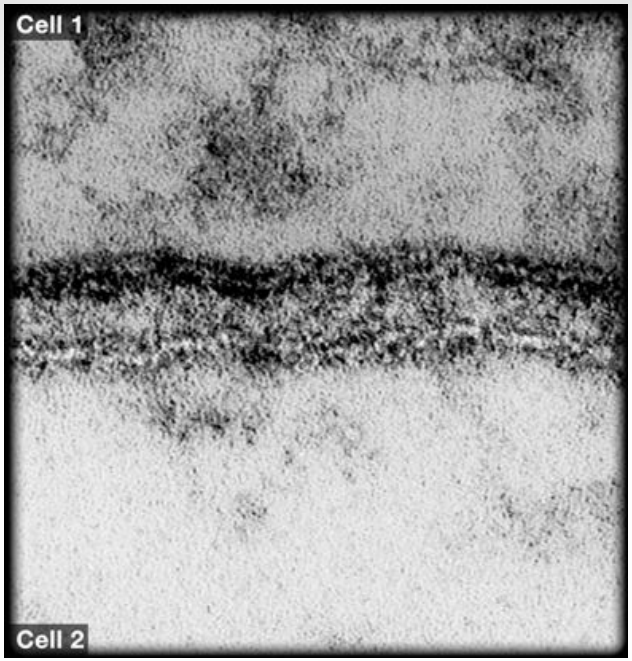
General Cell Functions *(continued)*

- Performed by some cells
  - Cell division
    - make more cells of the same type
    - help maintain the tissue by providing new cells

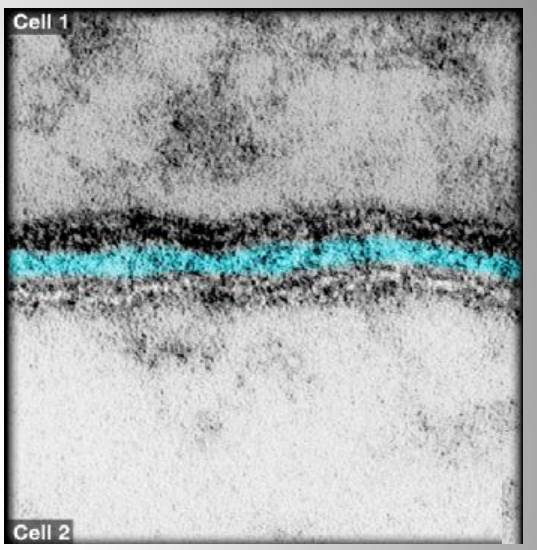
Plasma Membrane

Inner leaflet

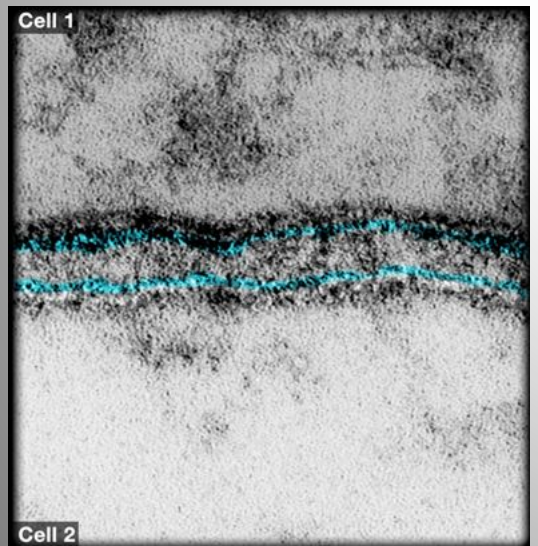


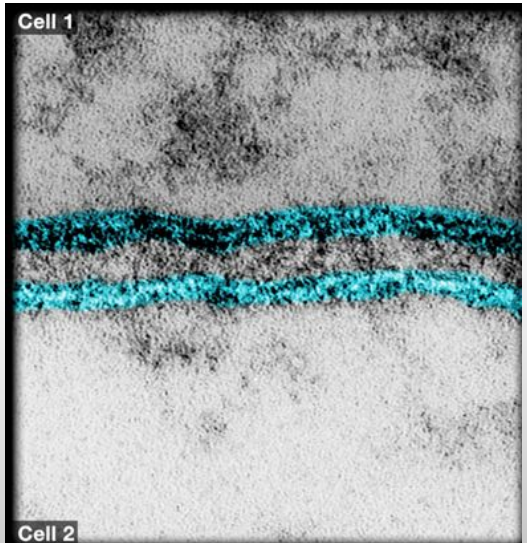


Extracellular matrix

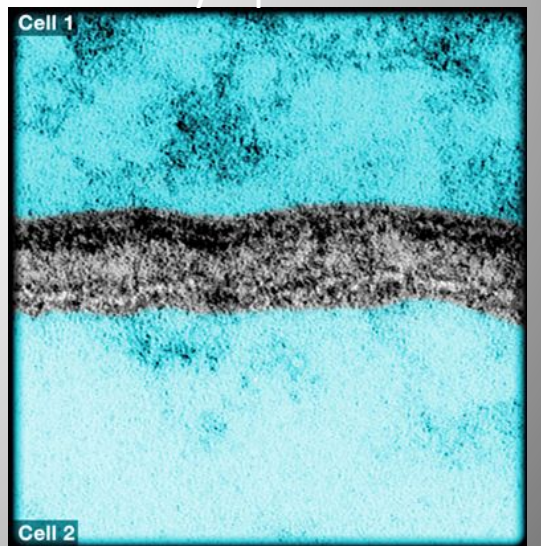


Outer leaflet





Cytoplasm

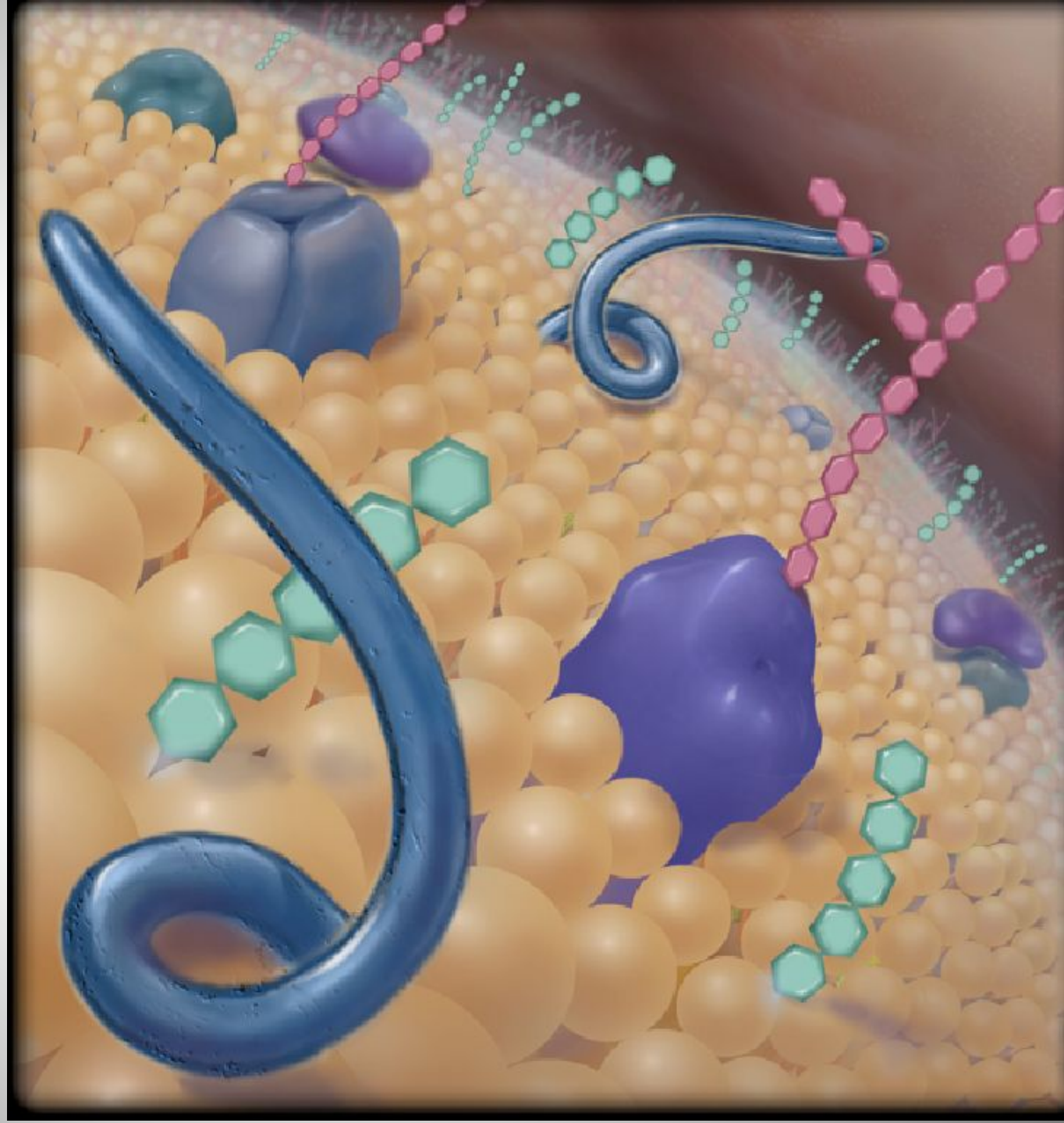


Components of Plasma Membrane

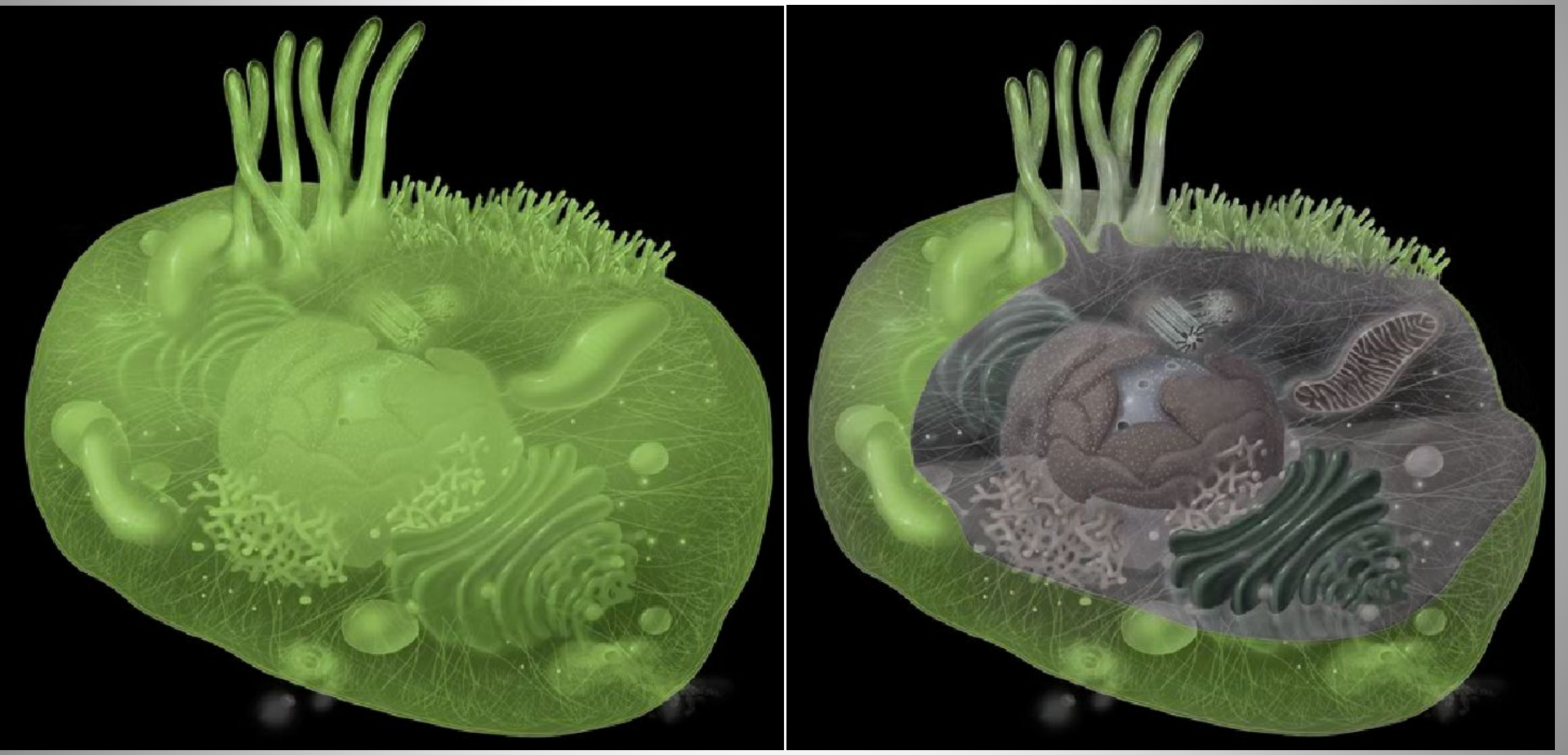
Membrane Lipids

Membrane Proteins

Membrane Carbohydrates

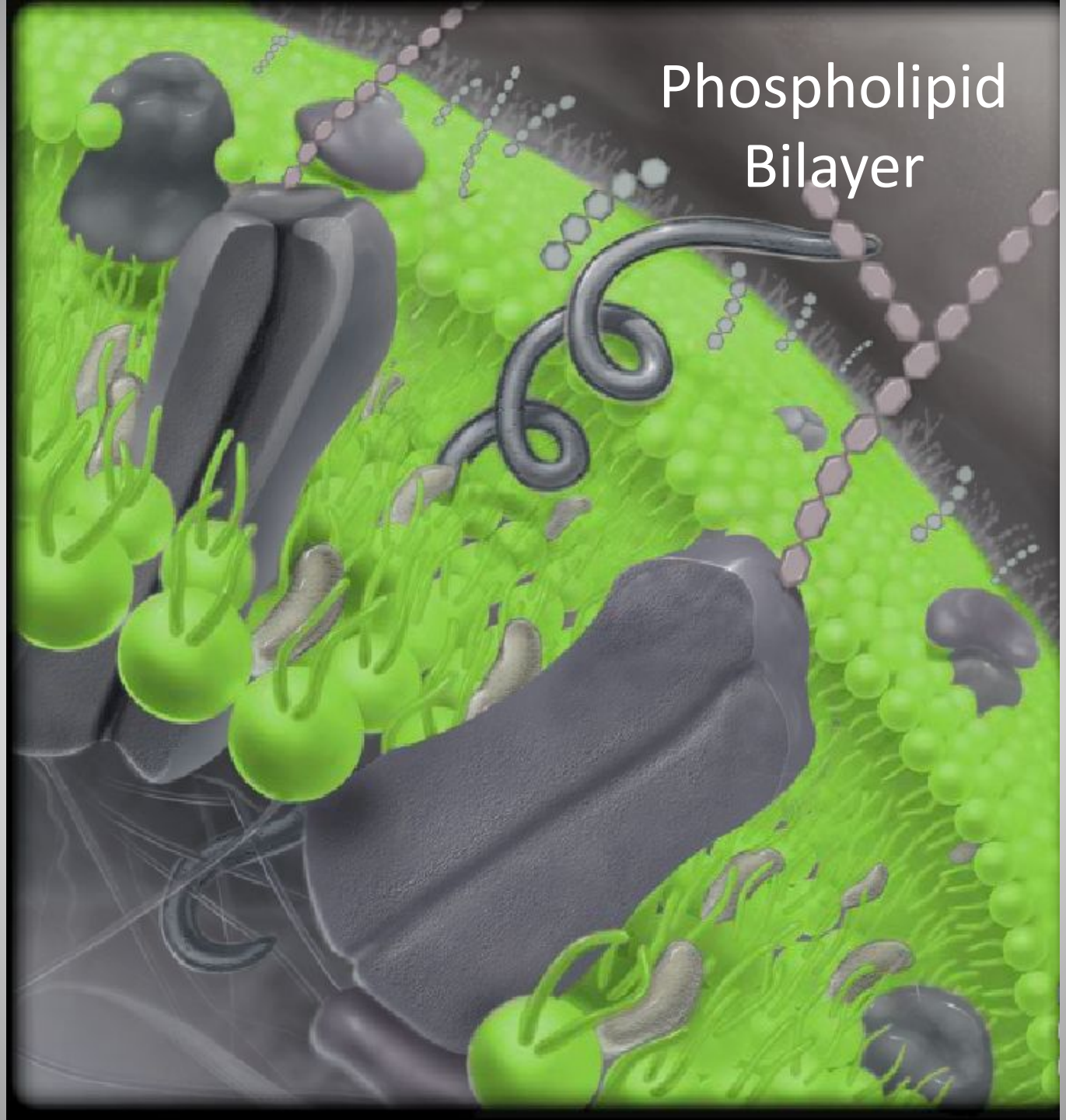


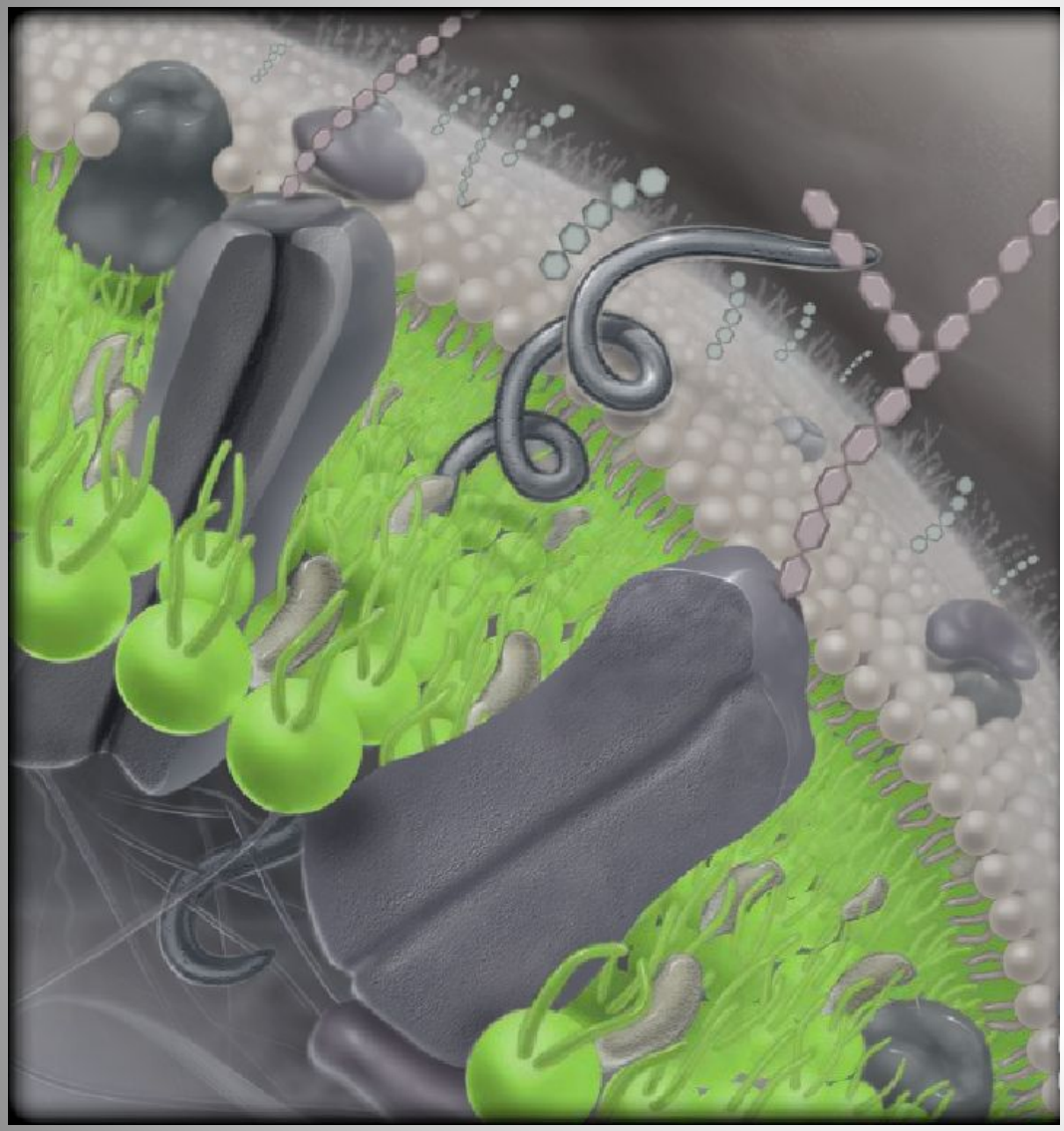
Plasma Membrane

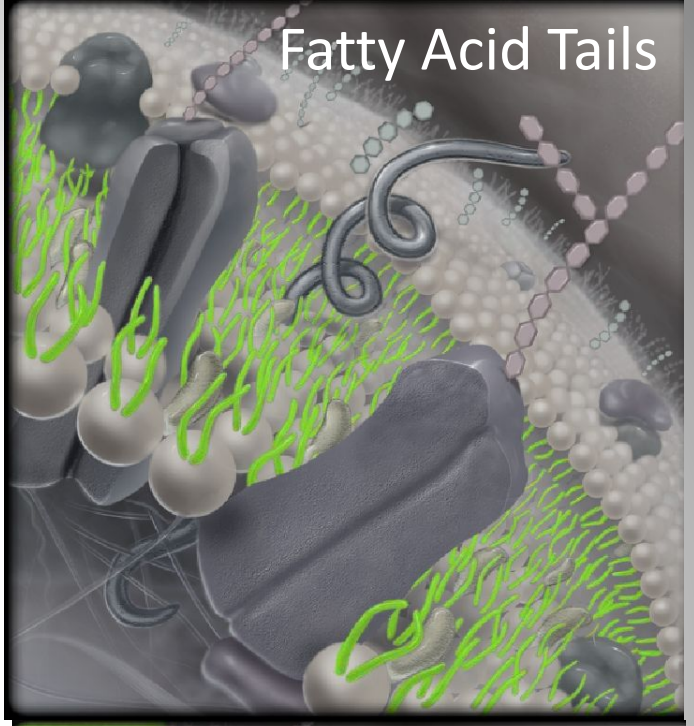


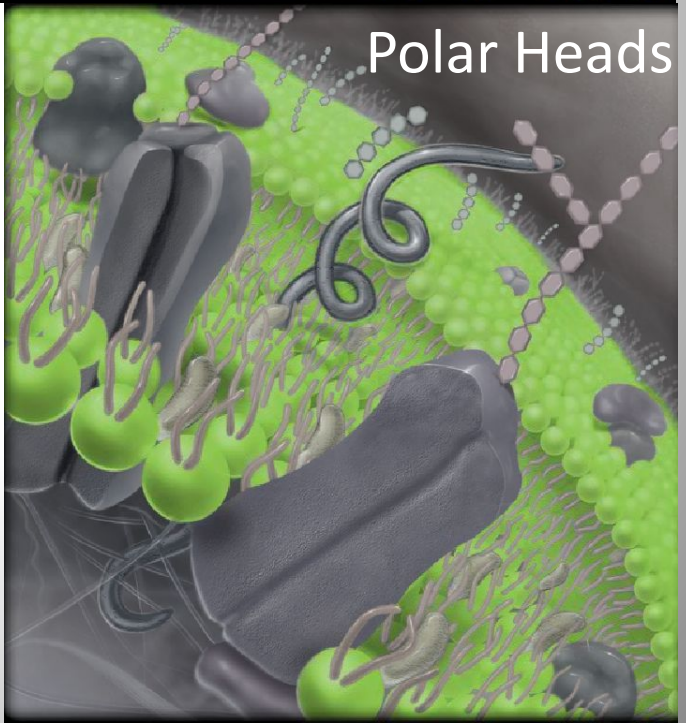
Chemical Structure of the Plasma Membrane: Lipid Components

- **Phospholipids**
  - Most membrane lipids of this type
  - Polar “head” and two hydrophobic “tails”
  - Form two parallel sheets of molecules
  - Lie tail to tail with tails forming internal area membrane
  - Head directed outward
  - Structure termed **phospholipid bilayer**
  - Ensures cytosol and fluid surrounding cells remain separate
    - surrounding fluid termed **interstitial fluid**


Phospholipid
Bilayer



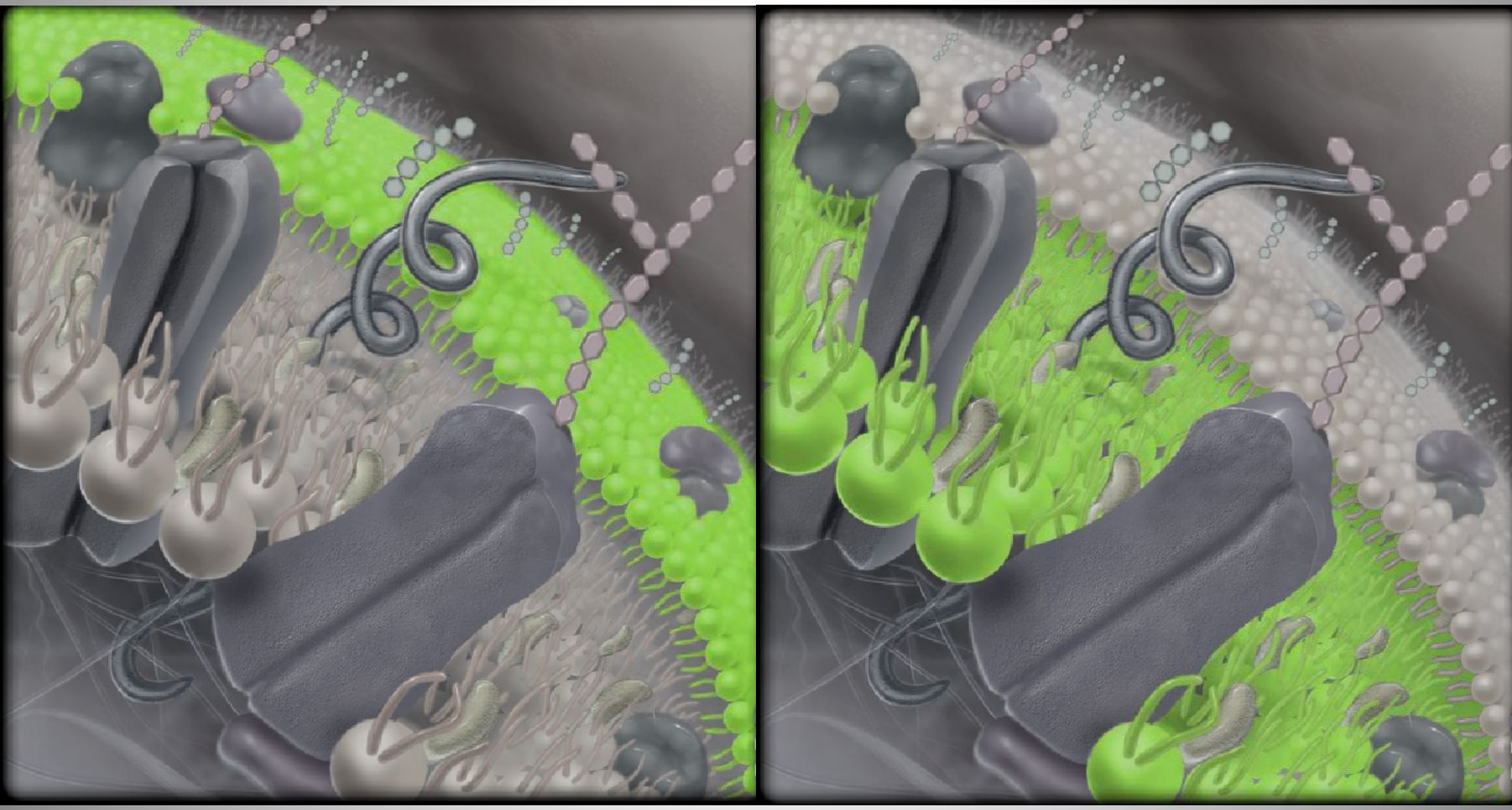




Phospholipid Molecules

Outer Leaflet

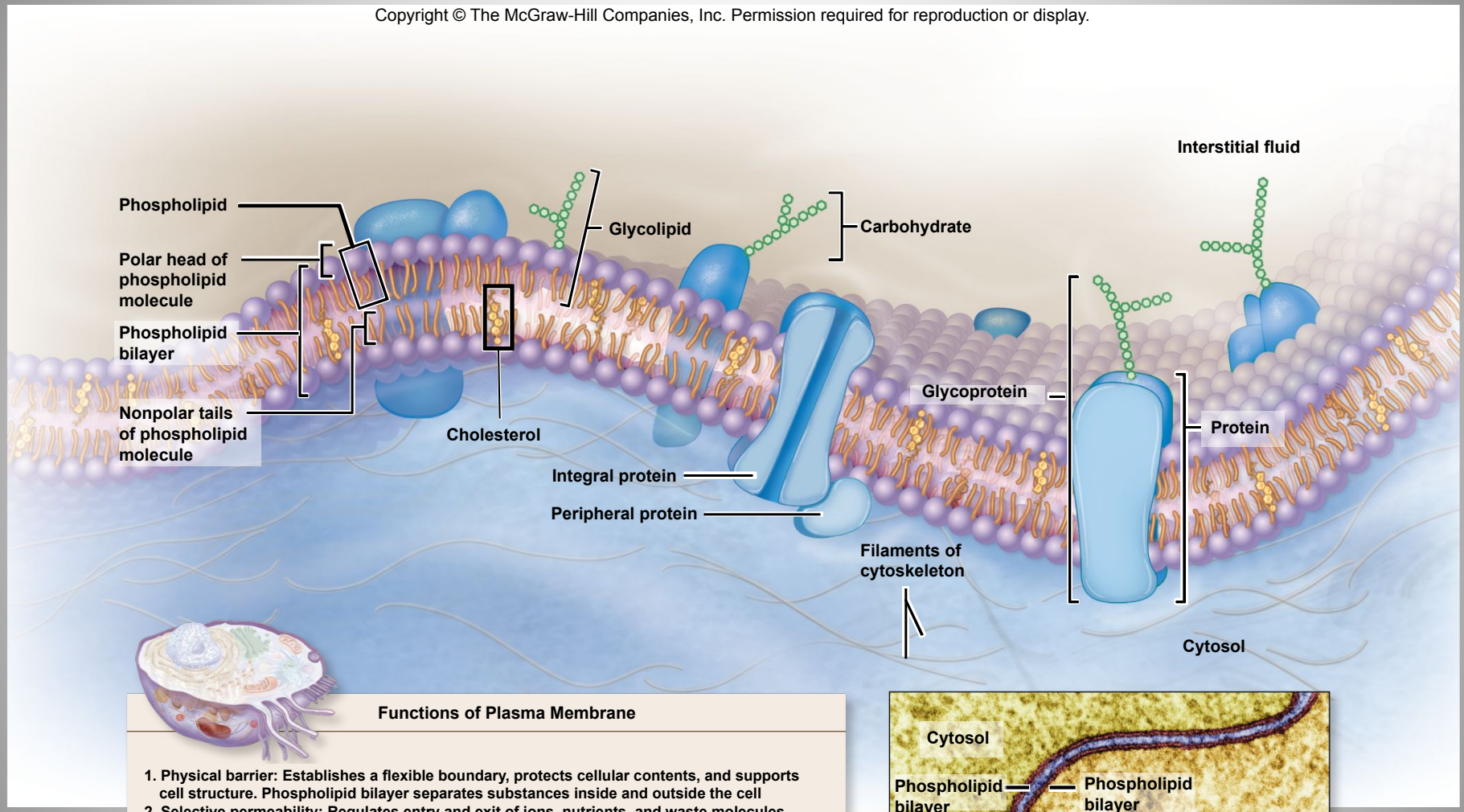
Inner Leaflet



Chemical Structure of the Plasma Membrane: Lipid Components

- **Cholesterol**
  - Scattered within phospholipid bilayer
  - Strengthens the membrane
  - Stabilizes the membrane against temperature extremes
- **Glycolipids**
  - Lipids with attached carbohydrate groups
  - Located on outer phospholipid region only
  - Helps to form the **glycocalyx**
    - the “coating of sugar” on cell’s surface

Figure 4.5



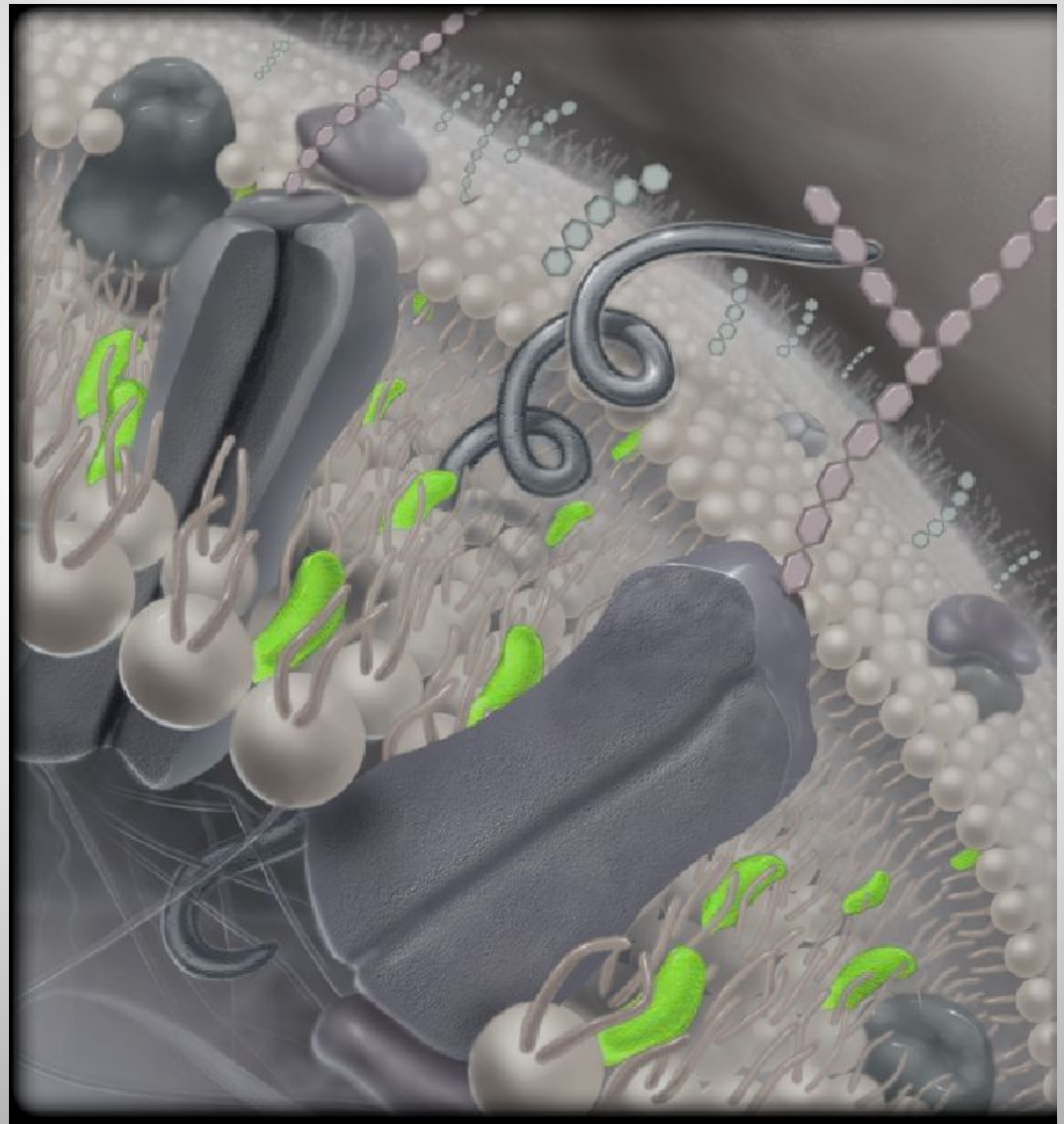
(a) Plasma membrane

(b) Phospholipid bilayer

b: © Don W. Fawcett/Photo Researchers, Inc.

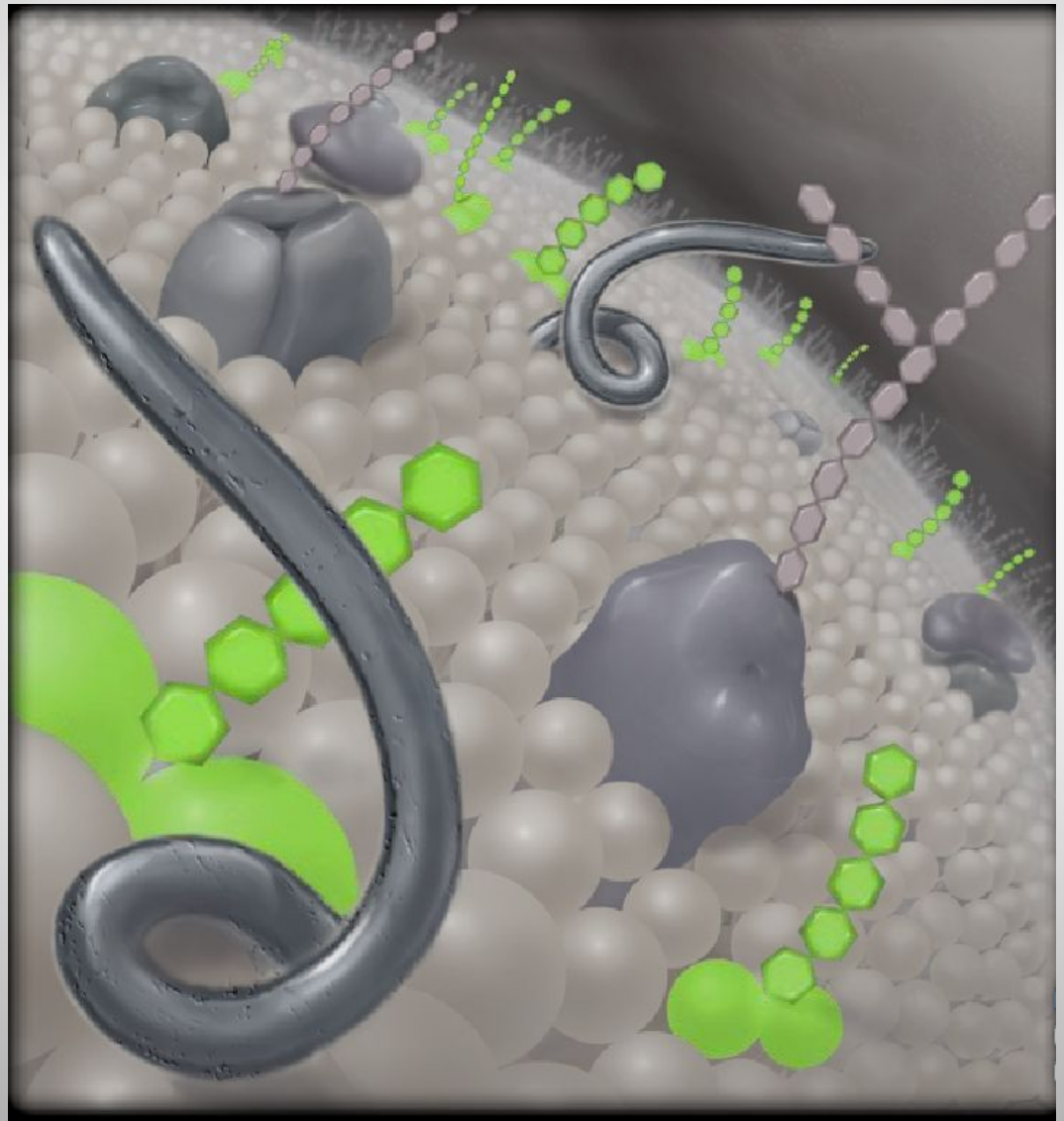
Membrane Lipid

Cholesterol



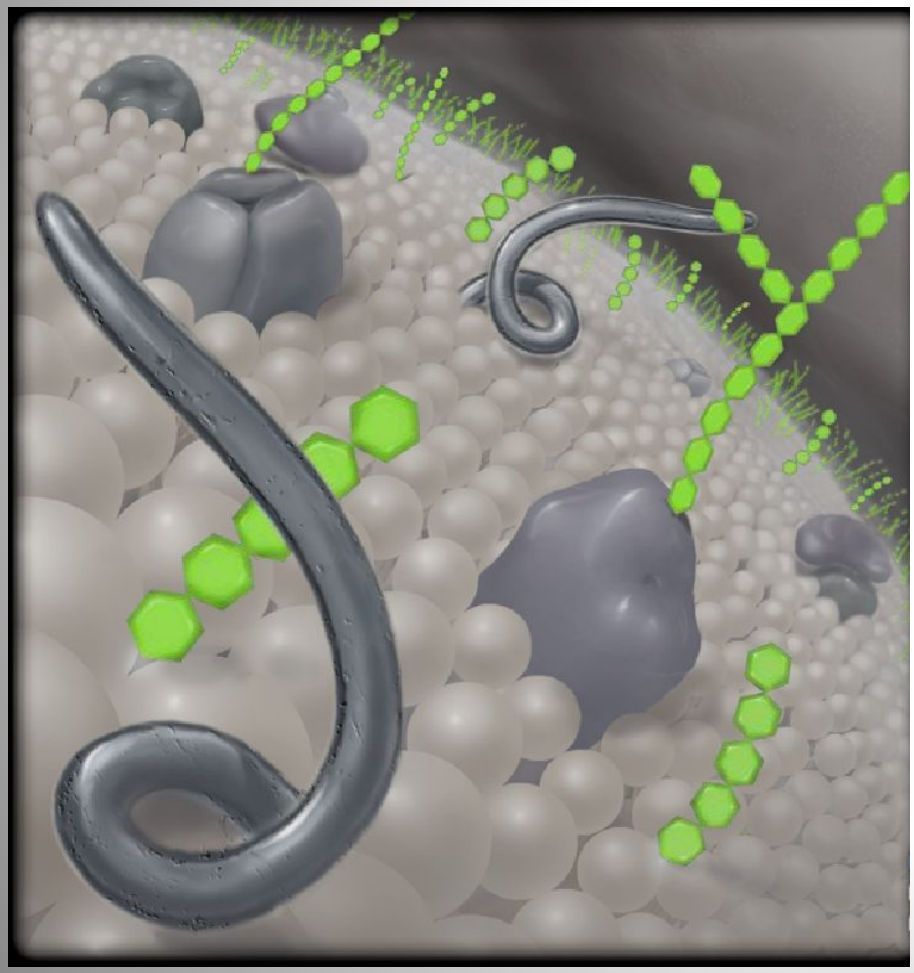
Membrane Lipid

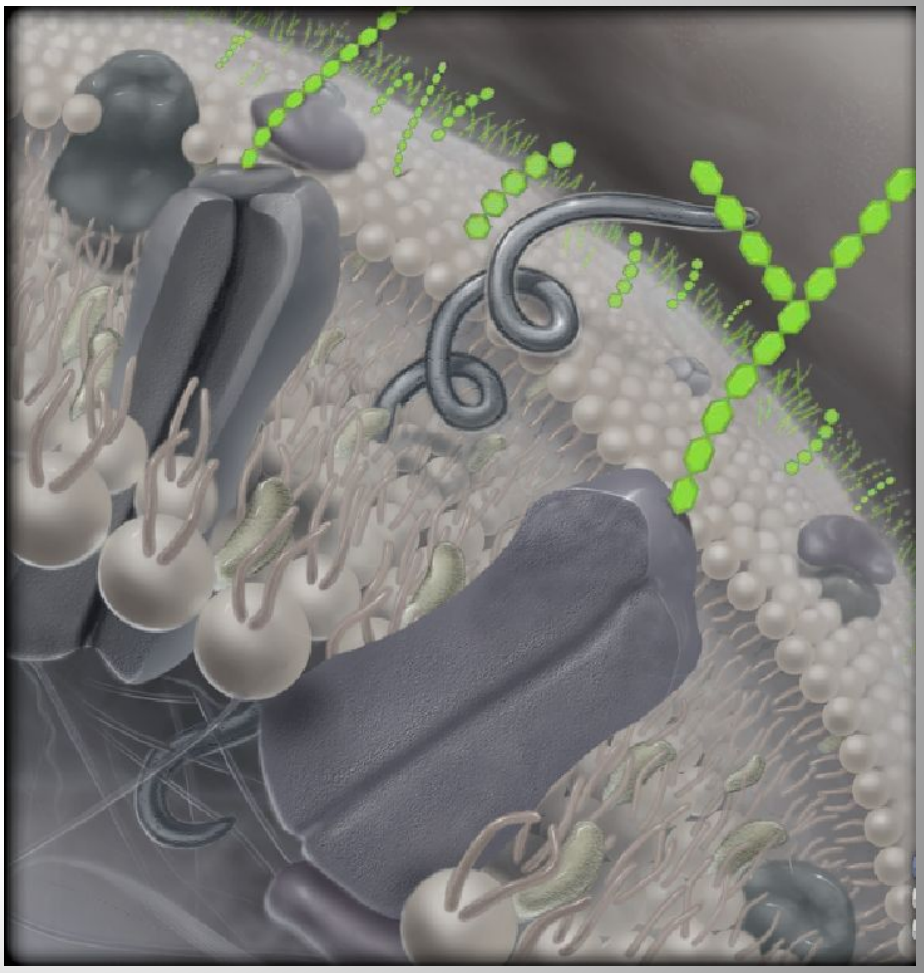
Glycolipid



Membrane Carbohydrates

Glycocalyx

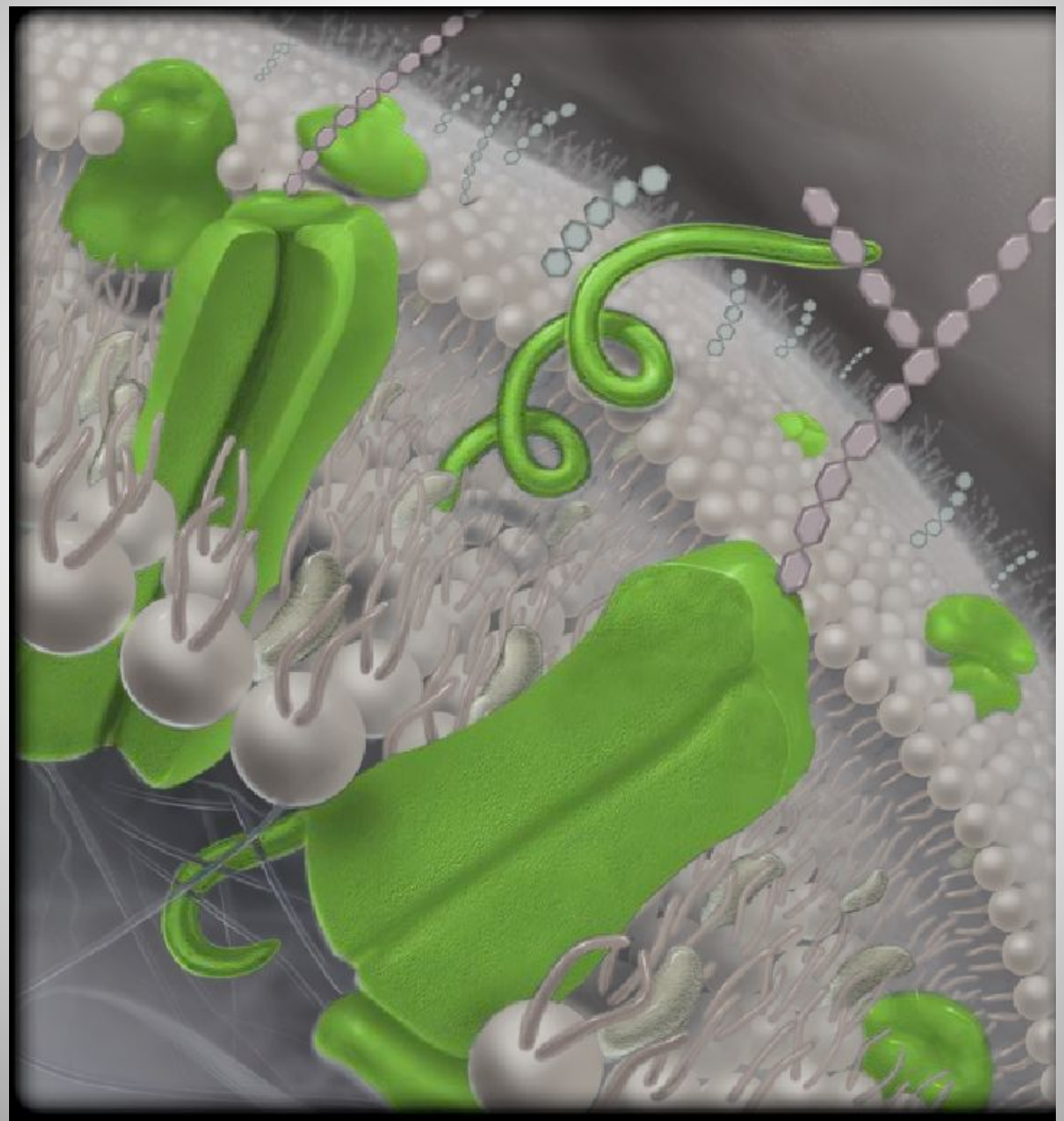


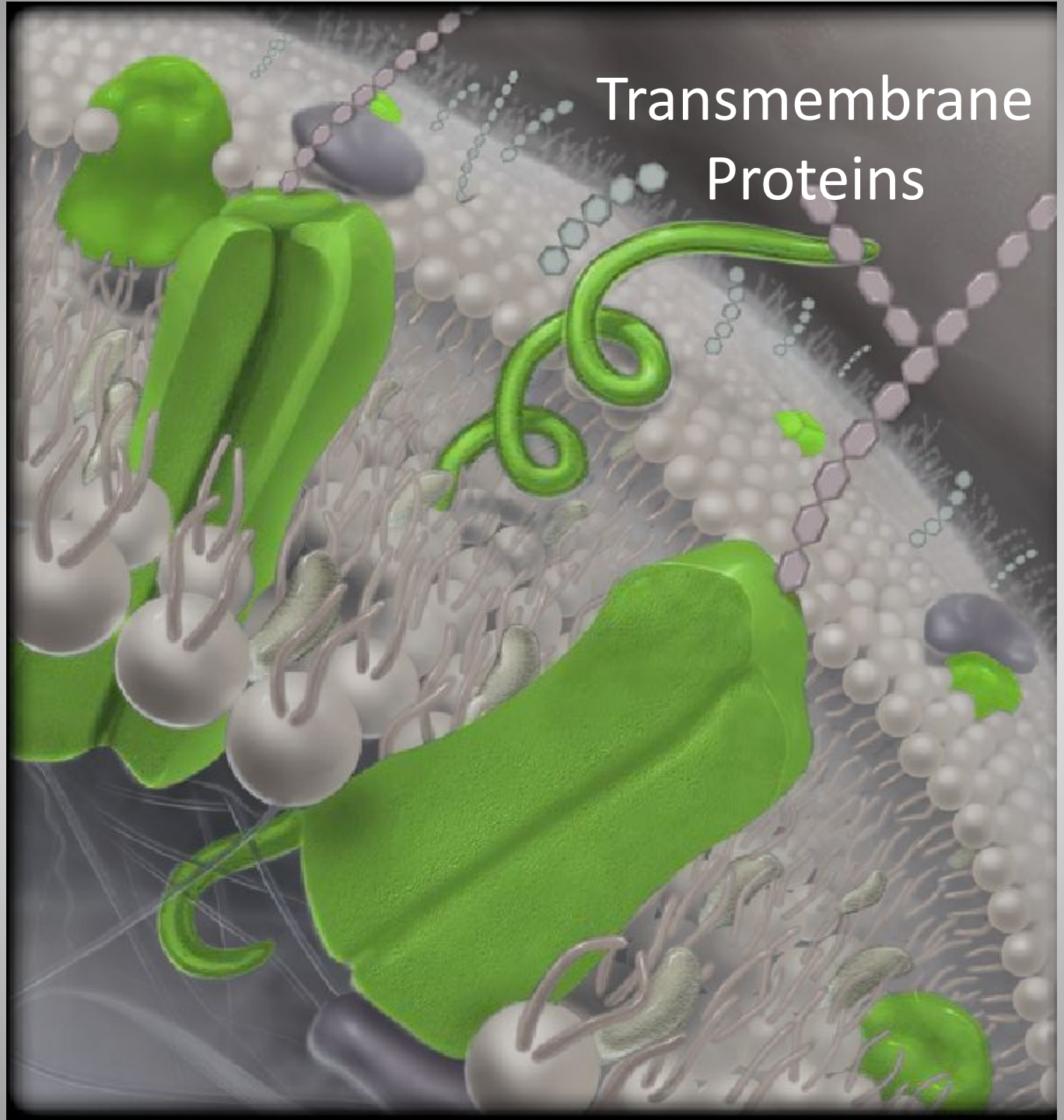


Chemical Structure of the Plasma Membrane: Membrane Proteins

- Membrane proteins
  - Compose half of plasma membrane by weight
  - Can “float” and move about fluid bilayer
  - Most of a membrane’s functions determined by resident proteins
  - Classified as integral or peripheral proteins

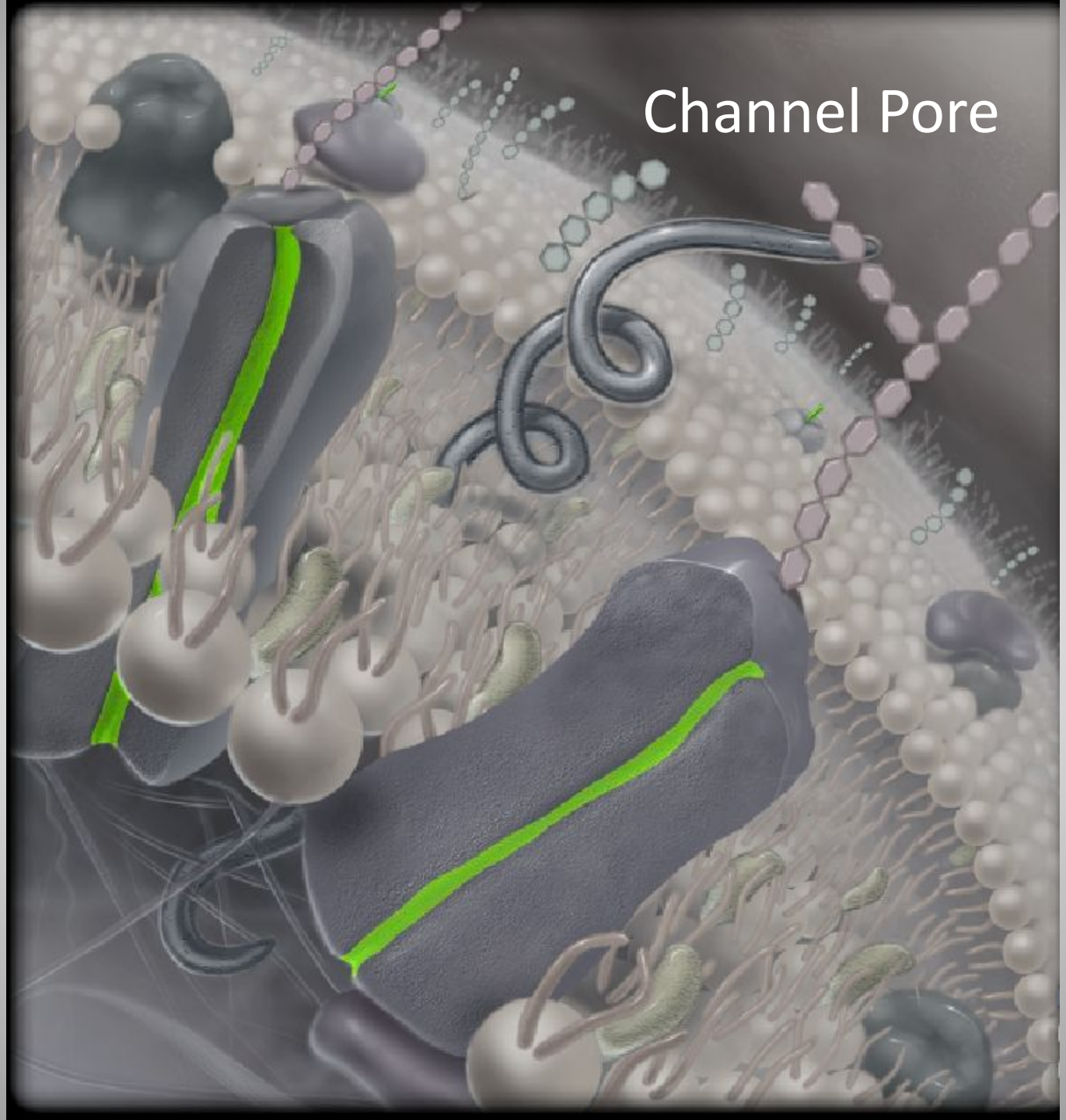
Membrane Protein

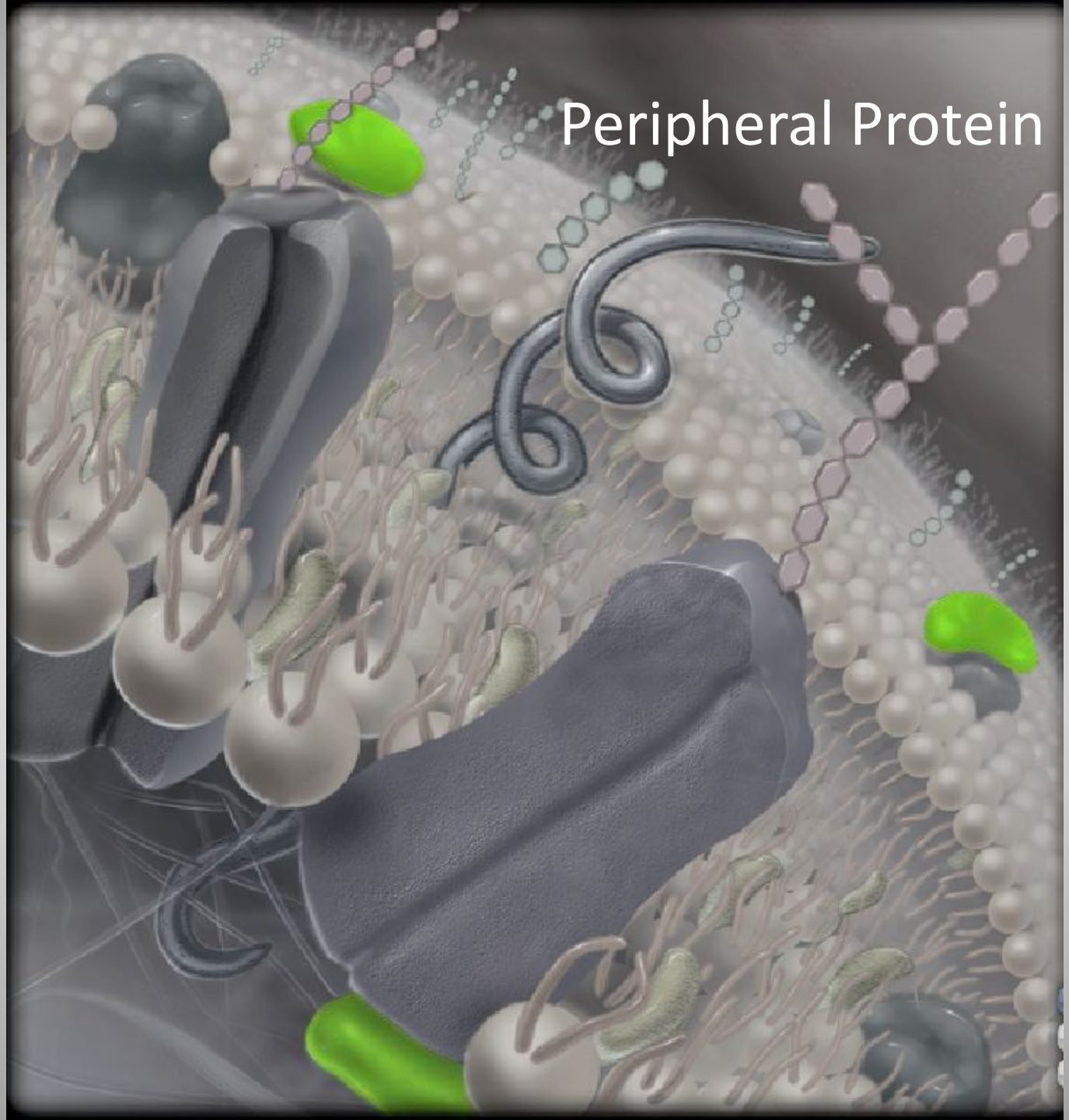


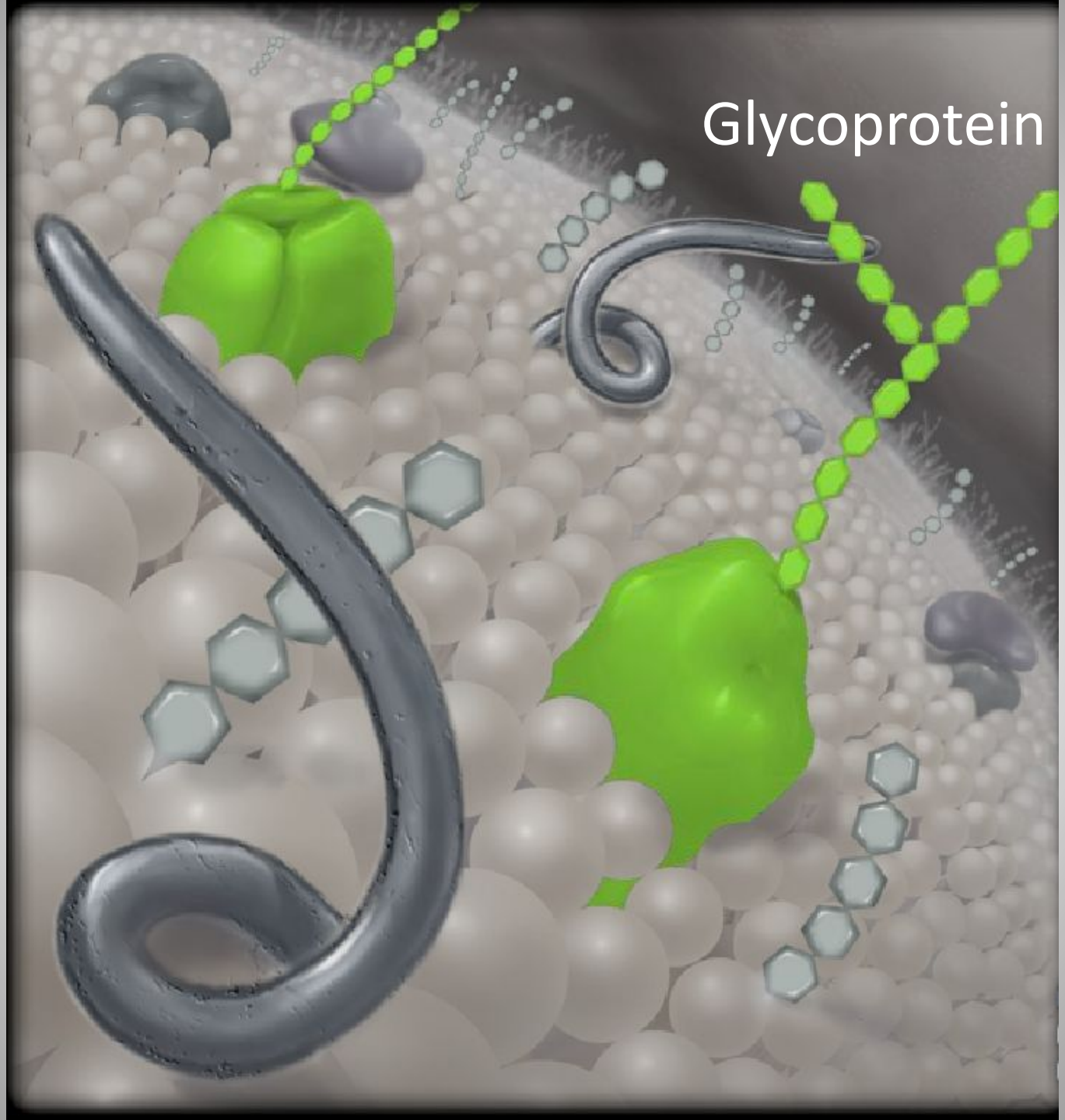

Transmembrane
Proteins

Chemical Structure of the Plasma Membrane: Membrane Proteins

- **Integral proteins**
  - Embedded within and extend across lipid bilayer
  - Hydrophobic regions interacting with hydrophobic interior
  - Hydrophilic regions interacting with hydrophilic regions
  - Often **glycoproteins** with carbohydrate portion
- **Peripheral proteins**
  - Not embedded in lipid bilayer
  - Attach loosely to surfaces of the membrane


Channel Pore


Peripheral Protein


Glycoprotein

Chemical Structure of the Plasma Membrane: Membrane Proteins

- Often categorized functionally
  - **Transport proteins**
    - regulate movement of substances across membrane
    - e.g., channels, carriers, and pumps
  - **Cell surface receptors**
    - bind **ligand** molecules released from a specific cell
    - bind receptors on another cell
    - e.g., neurotransmitters and hormones

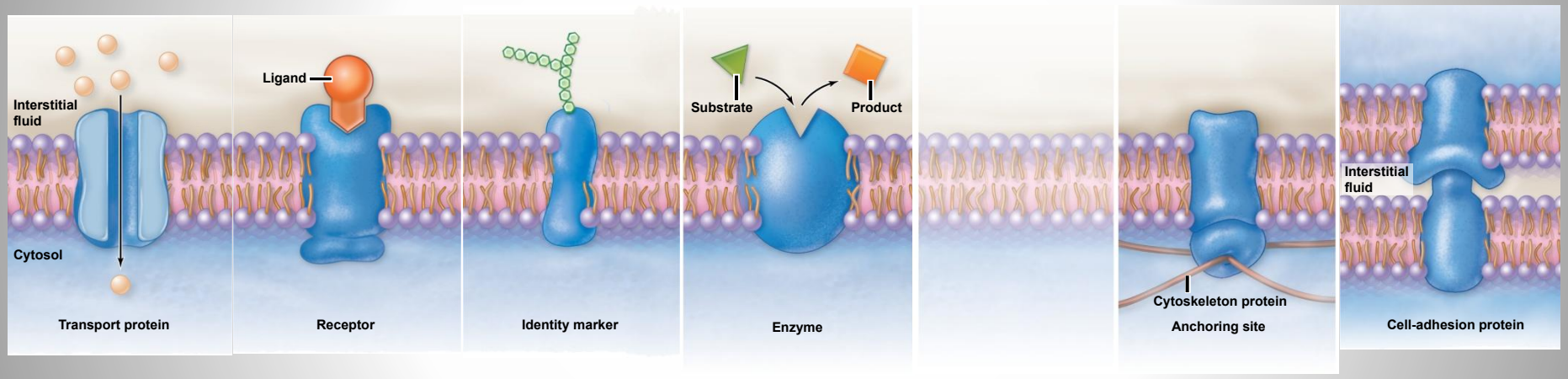
Chemical Structure of the Plasma Membrane: Membrane Proteins

- Often categorized functionally *(continued)*
  - **Identity markers**
    - communicate to other cells
    - e.g., immune system cells distinguishing healthy cells from foreign cells
  - **Enzymes**
    - catalyze chemical reactions

Chemical Structure of the Plasma Membrane: Membrane Proteins

- Often categorized functionally *(continued)*
  - **Anchoring sites**
    - Secure cytoskeleton to plasma membrane
  - **Cell-adhesion proteins**
    - Perform cell to cell attachments

Figure 4.6



Membrane Transport

- One important function of plasma membrane
  - Regulating movement of materials into and out of a cell
    - requires substances from interstitial fluid
    - requires waste elimination into interstitial fluid
    - occurs through processes of **membrane transport**
    - can be categorized as passive or active transport

Membrane Transport

- **Passive processes** of membrane transport
  - Do not require energy
  - Depend on substances moving down concentration gradient
    - move from where there is more of a substance to where there is less
  - Two types:
    - diffusion
    - osmosis

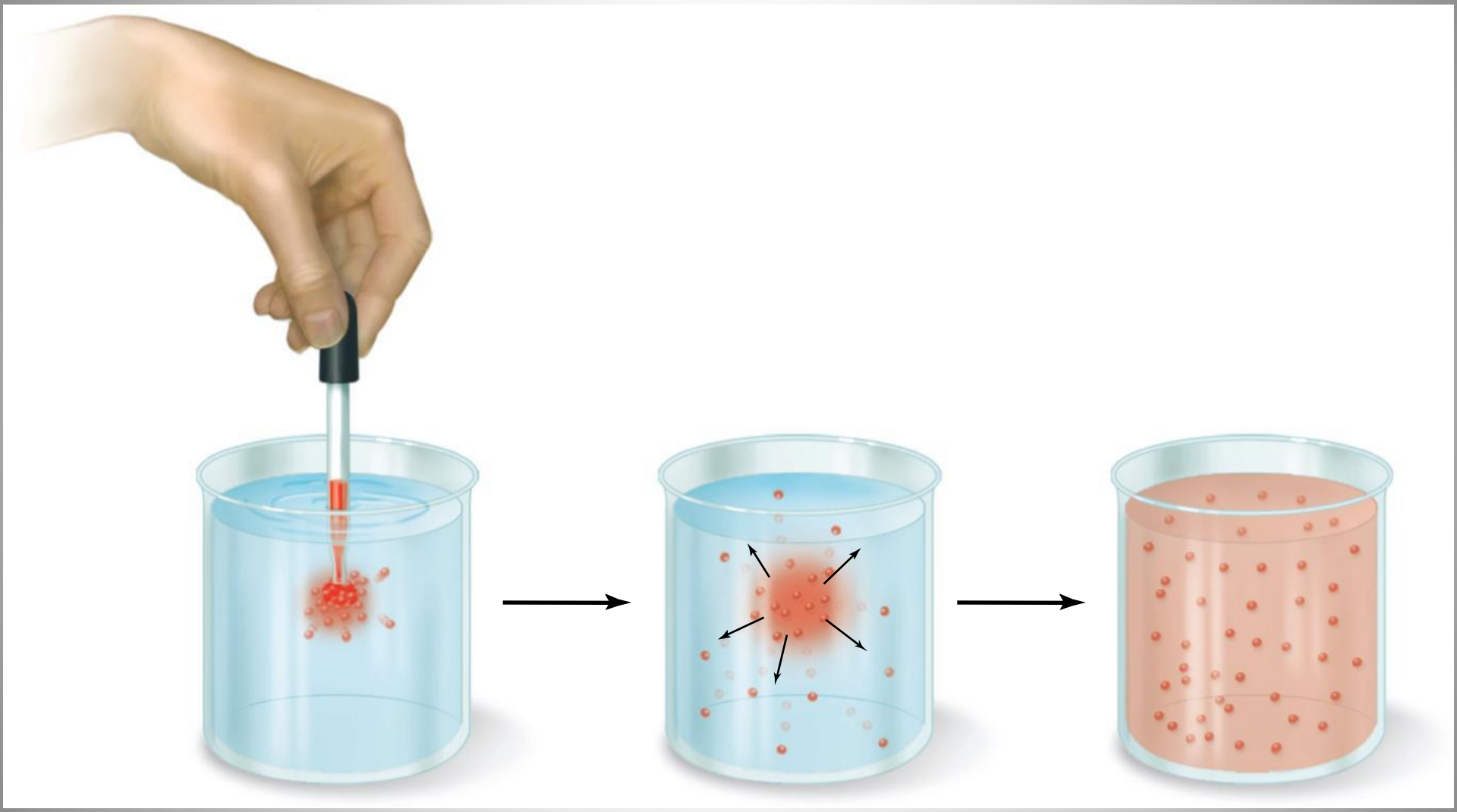
Membrane Transport

- Active processes of membrane transport
  - Require energy
  - E.g., movement of a substance up its concentration gradient
    - termed active transport
  - E.g., release of a membrane-bound vesicle
    - termed vesicular transport

Membrane Transport—
Passive Processes: Diffusion

- Environmental conditions affecting rate of diffusion
  - "Steepness" of concentration gradient
    - measure of the difference in concentration between two areas
    - steeper gradient with a faster rate of diffusion
  - Temperature
    - reflects kinetic energy and random movement
    - higher movement with higher temperature
    - results in faster rate of diffusion

Figure 4.7

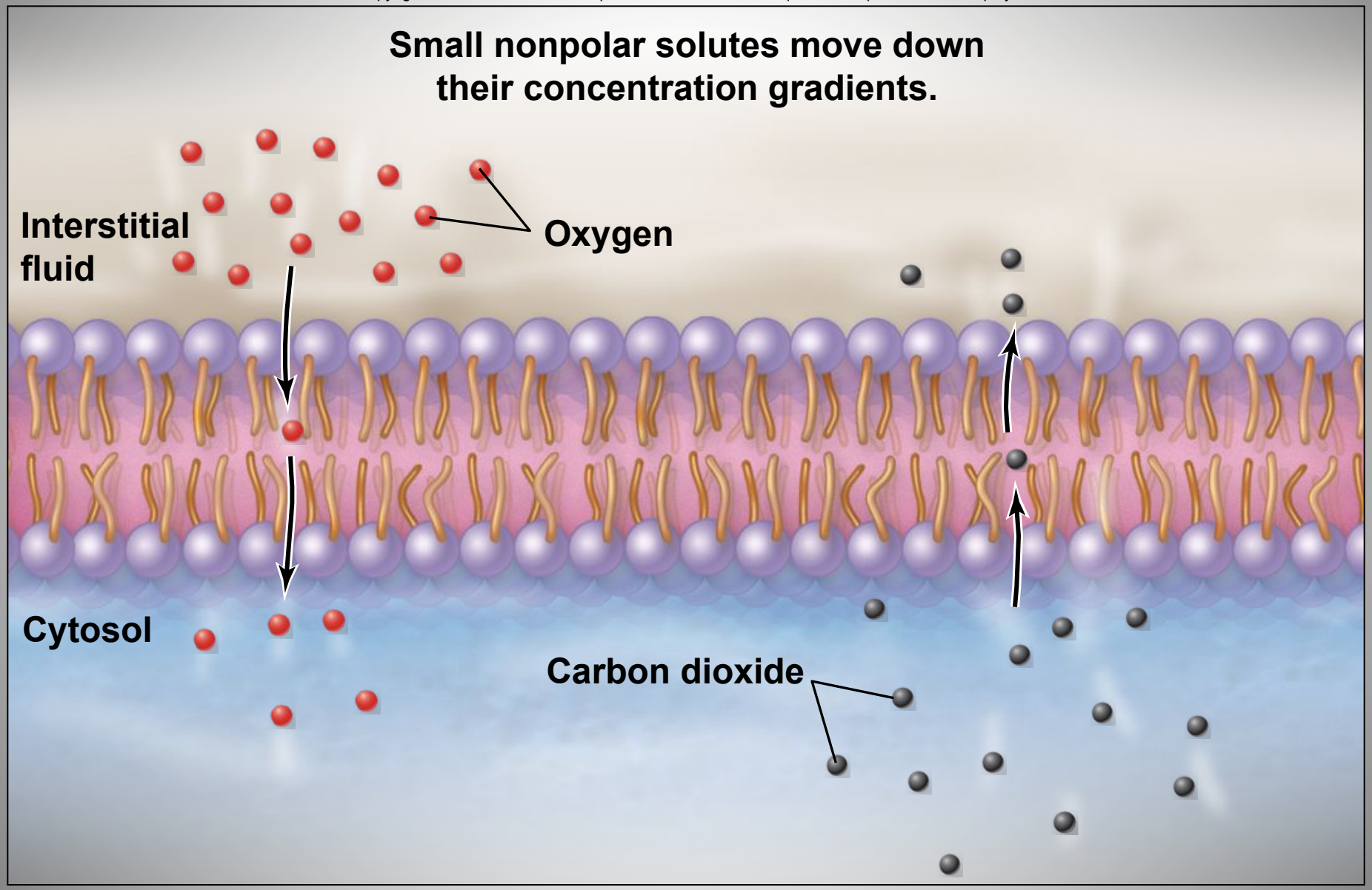


Membrane Transport—
Passive Processes: Diffusion

Cellular Diffusion

- **Simple diffusion**
  - Molecules passing between phospholipid molecules
  - Solutes small and nonpolar
  - Include respiratory gases (O_2 and CO_2), some fatty acids, ethanol, urea
  - Cannot be regulated by plasma membrane
  - Movement dependent on concentration gradient alone
  - Continue to move as long as gradient exists

Figure 4.8



Membrane Transport—
Passive Processes: Diffusion

Cellular Diffusion *(continued)*

- **Facilitated diffusion**
  - Transport process for small charged or polar solutes
  - Require assistance from plasma membrane proteins
  - Two types of facilitated diffusion
    - channel-mediated diffusion
    - carrier-mediated diffusion
  - Maximum rate of transport determined by number of channels and carriers
    - higher rate with greater number of transport proteins

Membrane Transport—
Passive Processes: Diffusion

Cellular Diffusion *(continued)*

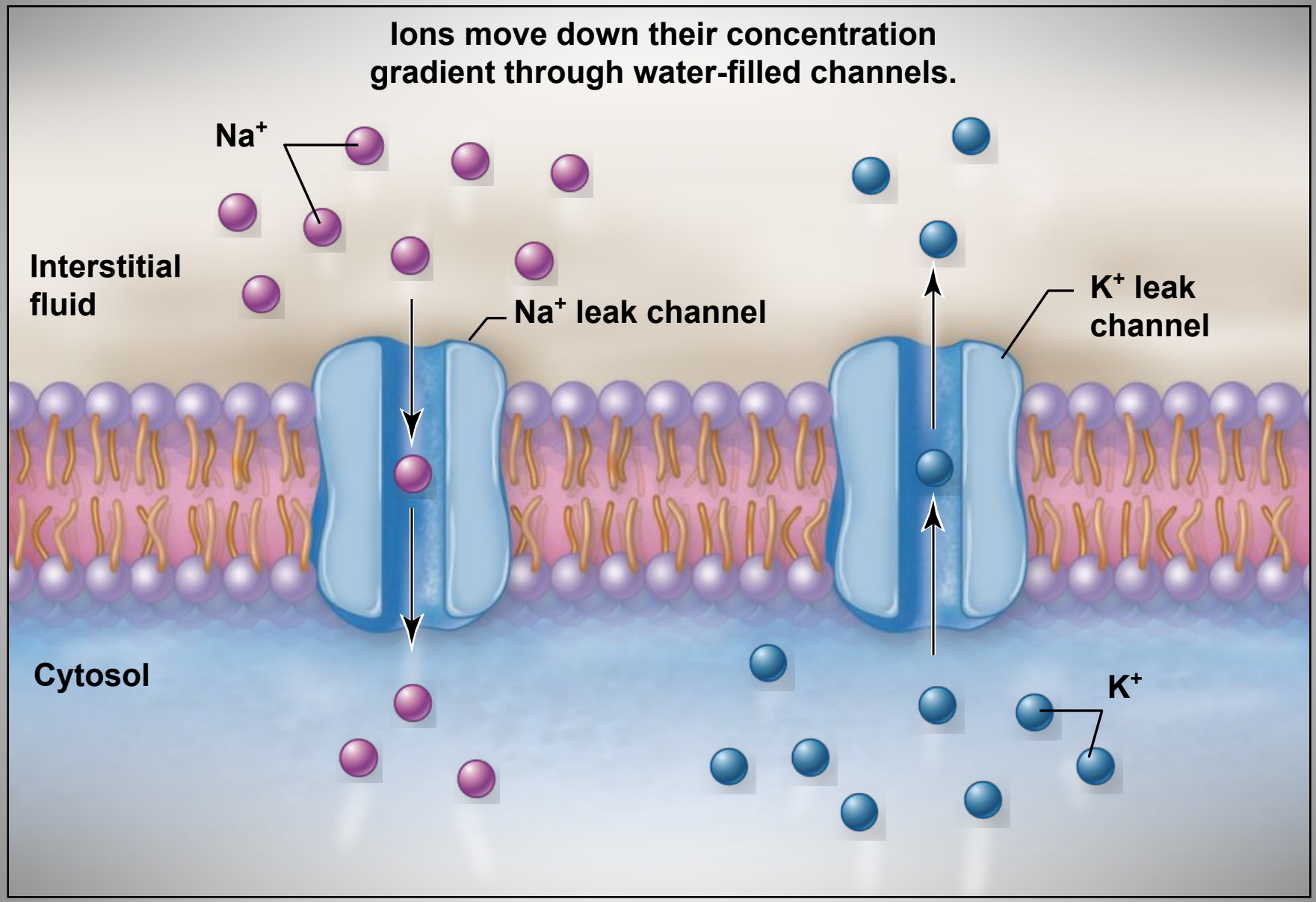
- **Facilitated diffusion**
  - Transport process for small charged or polar solutes
  - Require assistance from plasma membrane proteins
  - Two types of facilitated diffusion
    - channel-mediated diffusion
    - carrier-mediated diffusion
  - Maximum rate of transport determined by number of channels and carriers
    - higher rate with greater number of transport proteins

Membrane Transport—
Passive Processes: Diffusion

Cellular Diffusion *(continued)*

- **Channel-mediated diffusion**
  - Movement of small ions through water-filled protein channels
  - Channels specific for one ion type
  - Leak channels
    - continuously open
  - Gated channel
    - usually closed
    - open in response to stimulus

Figure 4.9a



(a) Channel-mediated diffusion

Membrane Transport—
Passive Processes: Diffusion

Cellular Diffusion *(continued)*

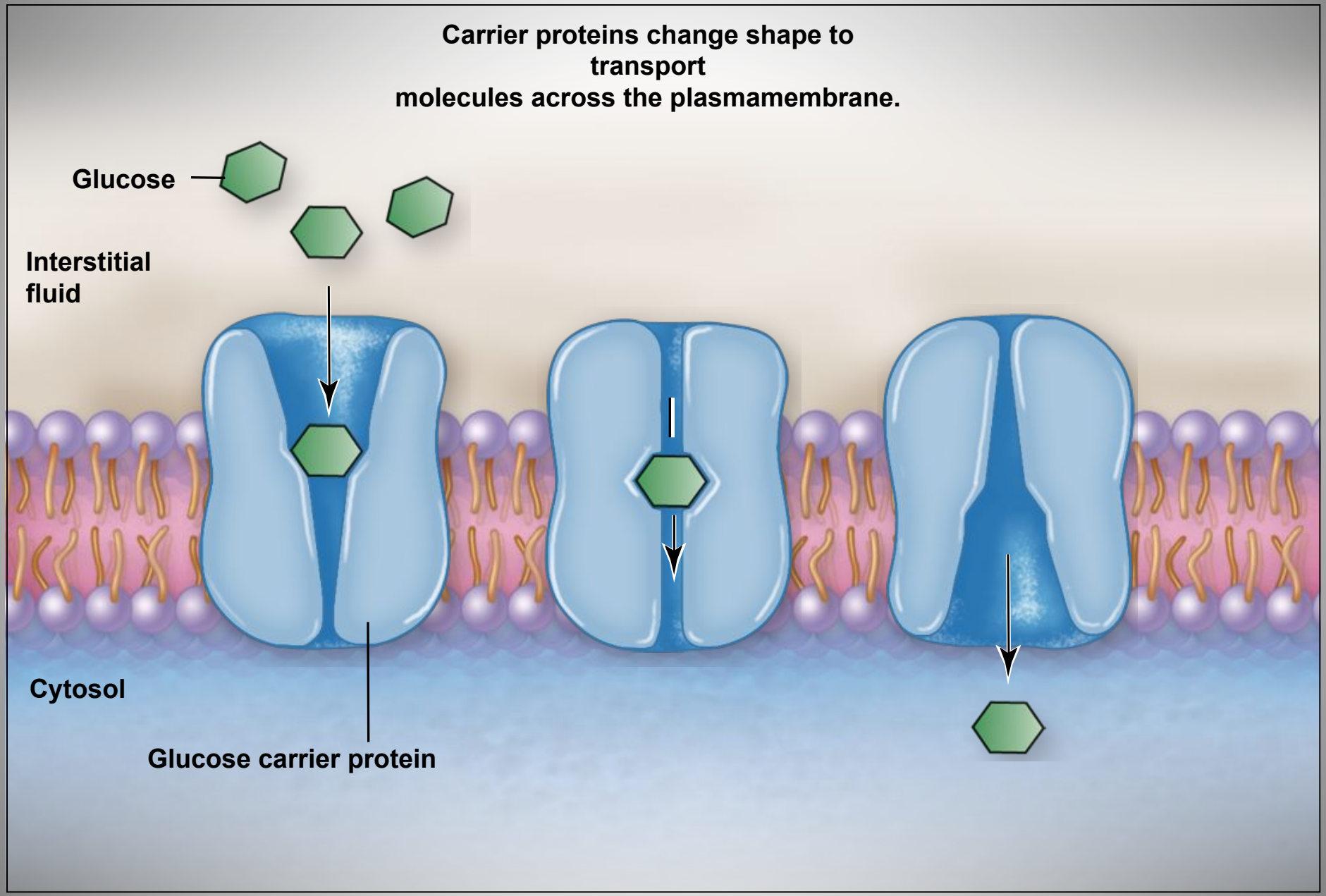
- Na^+ channels
  - Na^+ leak channels
    - allow Na^+ to pass through continuously
  - Chemically gated Na^+ channels
    - allow Na^+ to move through in response to a particular chemical

Membrane Transport—
Passive Processes: Diffusion

Cellular Diffusion *(continued)*

- **Carrier-mediated diffusion**
  - Small, polar molecules assisted across membrane by carrier protein
  - Transport substances such as glucose
  - Binding of substance causing change in carrier protein shape
  - Releases substances on other side of membrane
  - Move substances down their gradient
  - Carrier transporting only one substance termed a **uniporter**

Figure 4.9b



(b) Carrier-mediated

Membrane Transport—
Passive Processes: Osmosis

- **Osmosis**
  - Passive movement of water through **selectively permeable** membrane
    - membrane allowing passage of water
    - membrane preventing passage of most solutes
  - Occurs in response to differences in water concentration
    - different concentrations on either side of a membrane

Membrane Transport—
Passive Processes: Osmosis

Plasma Membrane: A Selectively Permeable Membrane

- Two ways water crosses membrane
  - "Slip between" molecules of phospholipid bilayer
  - Moves through integral protein water channels
    - termed **aquaporins**

Membrane Transport—
Passive Processes: Osmosis

Plasma Membrane: A Selectively Permeable Membrane *(continued)*

- Two types of solutes
  - **Permeable** solutes
    - pass through bilayer
    - small and nonpolar solutes
    - e.g., oxygen, carbon dioxide
  - **Nonpermeable** solutes
    - prevented from passing through bilayer
    - charged, polar, or large solutes
    - e.g., ions, glucose, proteins

Membrane Transport—
Passive Processes: Osmosis

Concentration Gradients Across the Plasma Membrane

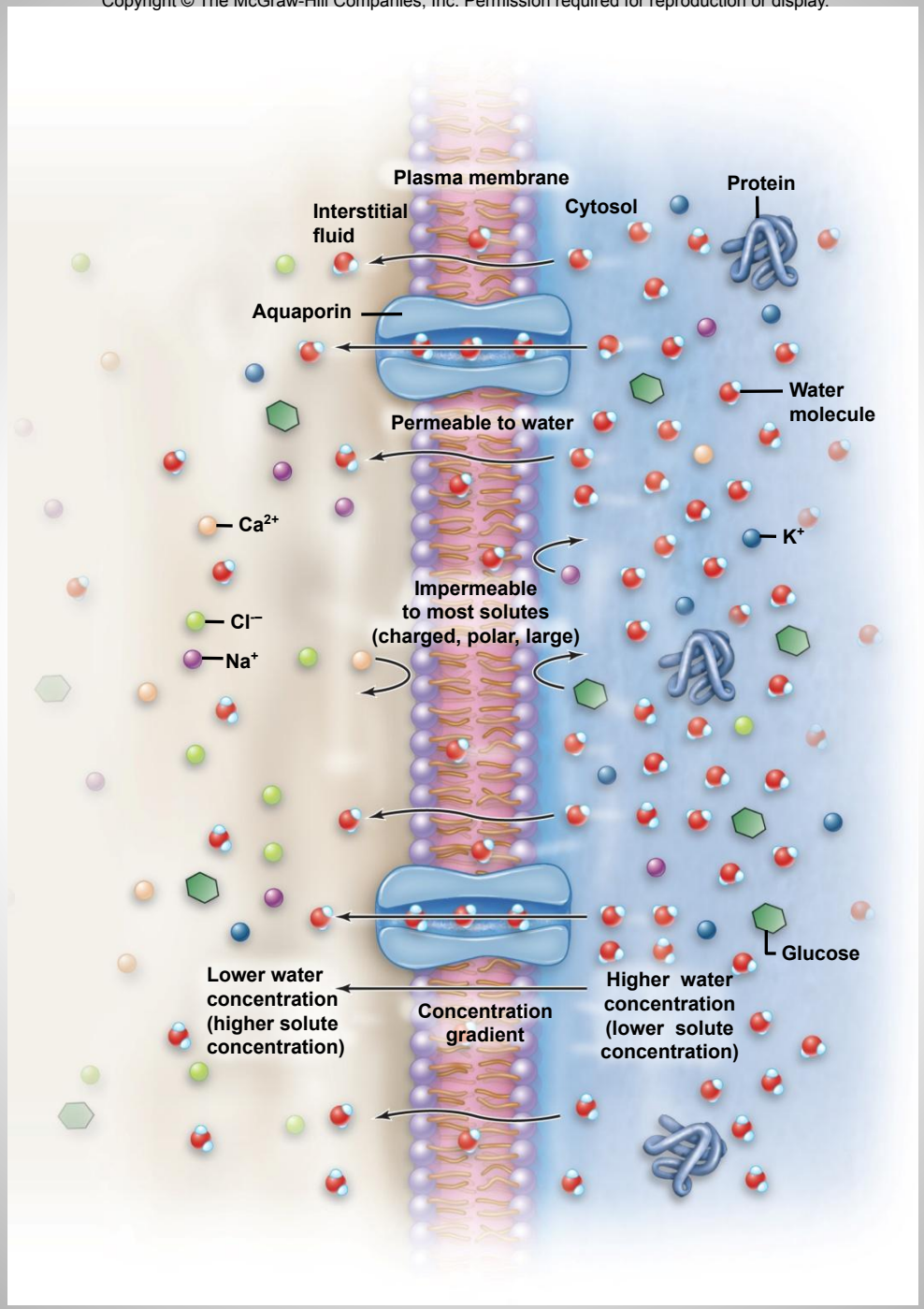
- Differences in solute concentration across membrane
  - May exist between cytosol and interstitial fluid
  - Also cause water concentrations to exist
  - Greater concentration of solutes with lower concentration of water

Membrane Transport—
Passive Processes: Osmosis

Movement of Water Into or Out of a Cell by Osmosis

- Net movement of water by osmosis
  - Dependent on concentration gradient between cytosol and solution
  - Moves down its gradient
  - E.g., moves from solution of 1% solutes to solution containing 3% solutes
  - Moves until equilibrium is reached
  - Equal concentration of water inside and outside cell
  - Moves toward solution with lower water concentration

Figure 4.10



Membrane Transport—
Passive Processes: Osmosis

Osmotic Pressure

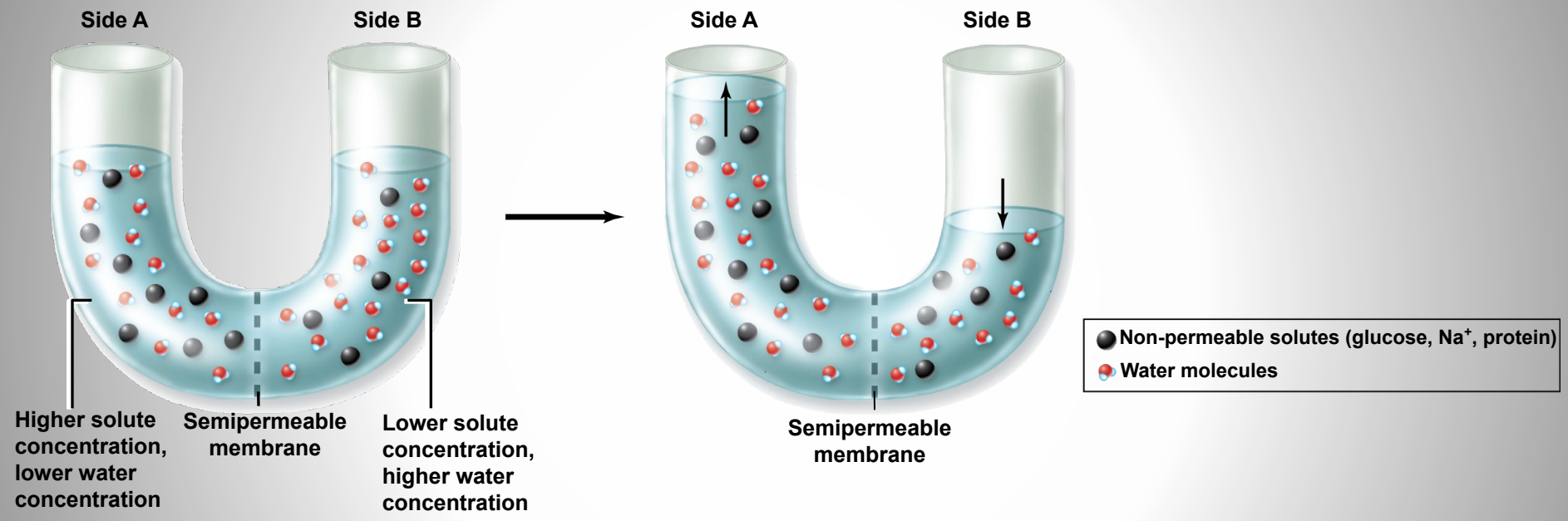
- Pressure exerted by movement of water across semipermeable membrane
- Due to difference in solution concentration
- Steeper gradient, more water moved by osmosis
- Steeper gradient, greater osmotic pressure

Membrane Transport—
Passive Processes: Osmosis

Osmotic Pressure *(continued)*

- **Figure 4.11**
  - Semipermeable membrane allowing for passage of water only
  - Side A with more solutes initially
  - Water moving from side B to side A by osmosis
  - Continues until fluids equal in concentration

Figure 4.11



Initial setup: Side A contains proportionately more solute and less water.

Final setup: Water moved by osmosis from side B down the water gradient to side A until the concentrations of side A and side B are equal.

Membrane Transport—
Passive Processes: Osmosis

Osmotic Pressure *(continued)*

- Can be measured indirectly
  - Could put stopper on side A in figure 4.11b
  - Could exert force to return fluid to original level
  - Would create **hydrostatic pressure** within the tube
    - the pressure exerted by a fluid on wall of its container
  - Osmotic pressure equal to hydrostatic pressure applied
    - = total pressure needed to return fluid to original level

Membrane Transport—
Passive Processes: Osmosis

Osmosis and Tonicity

- Cell gains or loses water with osmosis
  - Accompanying change in cell volume and osmotic pressure
  - **Tonicity**
    - ability of a solution to change the volume or pressure of the cell by osmosis

Membrane Transport—
Passive Processes: Osmosis

Osmosis and Tonicity *(continued)*

- **Isotonic** solution
  - Both cytosol and solution with same relative concentration of solutes
  - E.g., physiological saline with a concentration of 0.9% NaCl
  - Isotonic to erythrocytes
  - No net movement of water

Membrane Transport—
Passive Processes: Osmosis

Osmosis and Tonicity *(continued)*

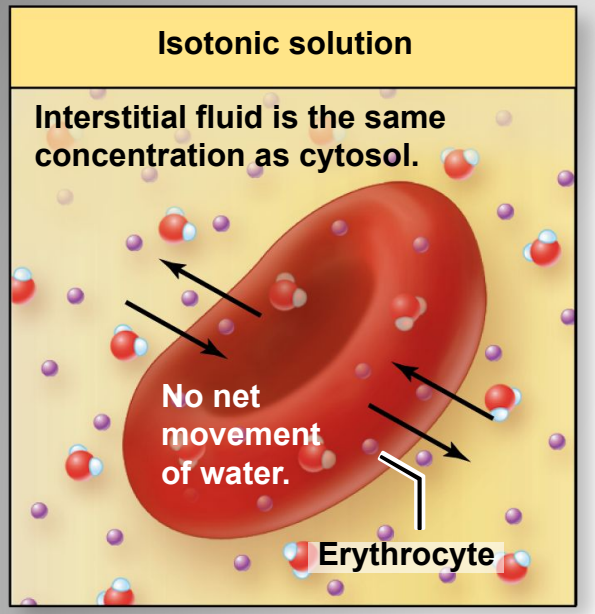
- **Hypotonic** solution
  - Solution with a lower concentration of solutes than cytosol
  - E.g., erythrocytes in pure water
  - Water moving down concentration gradient
    - from outside the cell to inside
  - Increased volume and pressure of cell
  - May cause cell **lysis** (rupture)
    - **hemolysis**, term for ruptured red blood cells

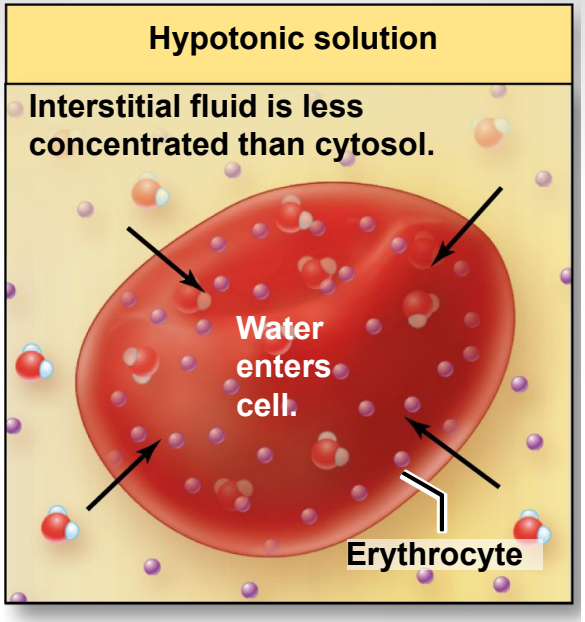
Membrane Transport—
Passive Processes: Osmosis

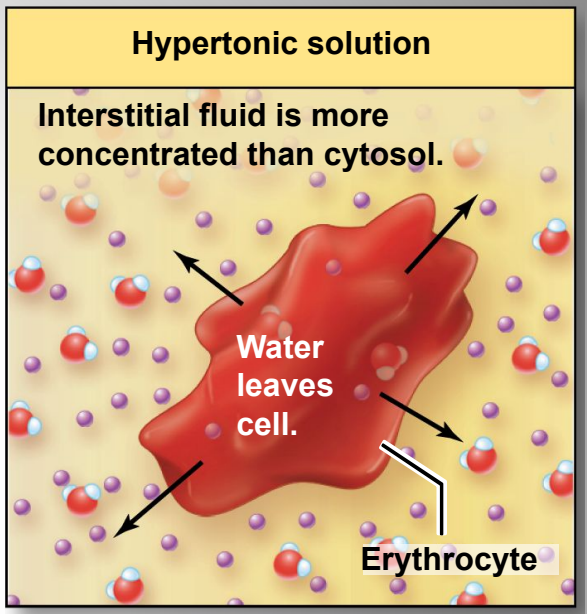
Osmosis and Tonicity *(continued)*

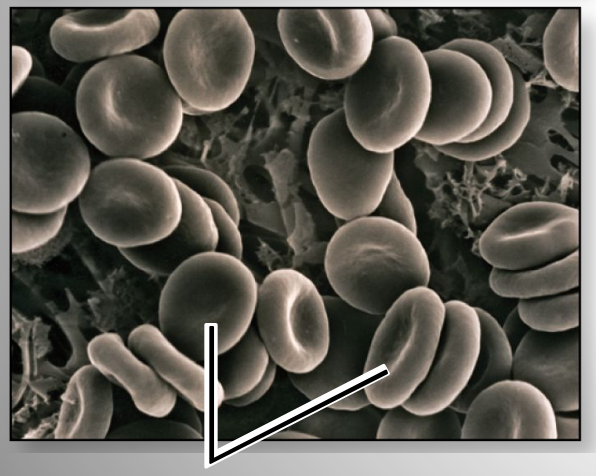
- **Hypertonic** solution
  - Solution with a higher concentration of solutes than cytosol
  - E.g., erythrocytes in 3% NaCl pure water
  - Water moves down concentration gradient
  - Moves from inside the cell to outside
  - Decreased volume and pressure of cell
  - May cause cell to shrink
    - termed **crenation**

Figure 4.12



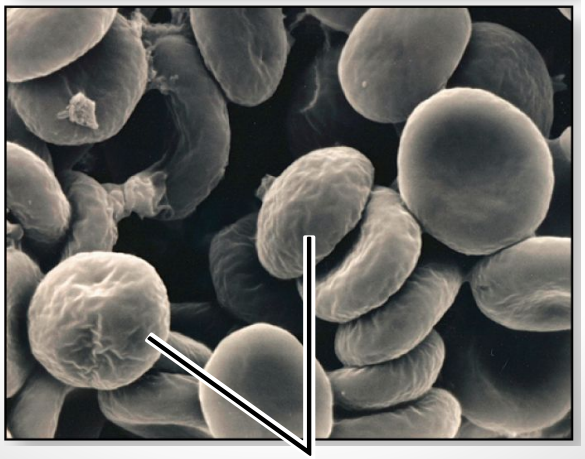






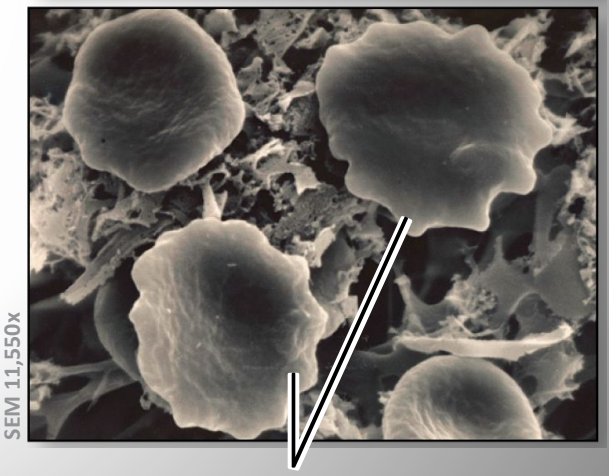
Normal erythrocytes

(a)



Erythrocytes nearing hemolysis

(b)



Erythrocytes undergoing crenation

(c)

Membrane Transport: Active Processes

Active Transport

- Opposes the movement of solutes by diffusion
- Solutes moved against a concentration gradient
- Maintains gradient between cell and interstitial fluid

Membrane Transport: Active Processes

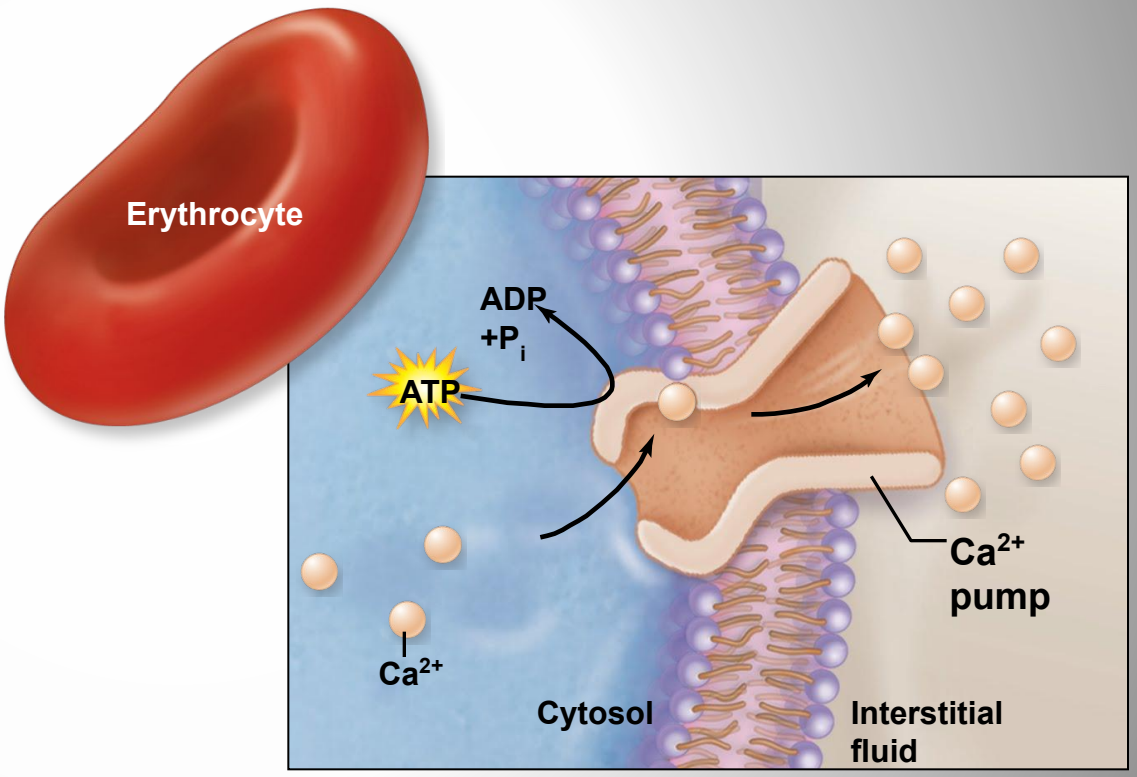
Active Transport *(continued)*

- Primary active transport
  - Uses energy directly from breakdown of ATP
  - Phosphate group added to transport protein
  - Results in a change in protein's shape
  - Results in movement of solute across membrane
  - Addition of phosphate to protein termed **phosphorylation**

Membrane Transport: Active Processes

- **Ion pumps**
  - Active transport proteins that move ions across membrane
  - Help cell maintain internal concentration of ions
  - E.g., Ca^{2+} pumps in plasma membrane of erythrocytes
    - prevent cell rigidity from accumulated calcium

Figure 4.13



Membrane Transport: Active Processes

Active Transport *(continued)*

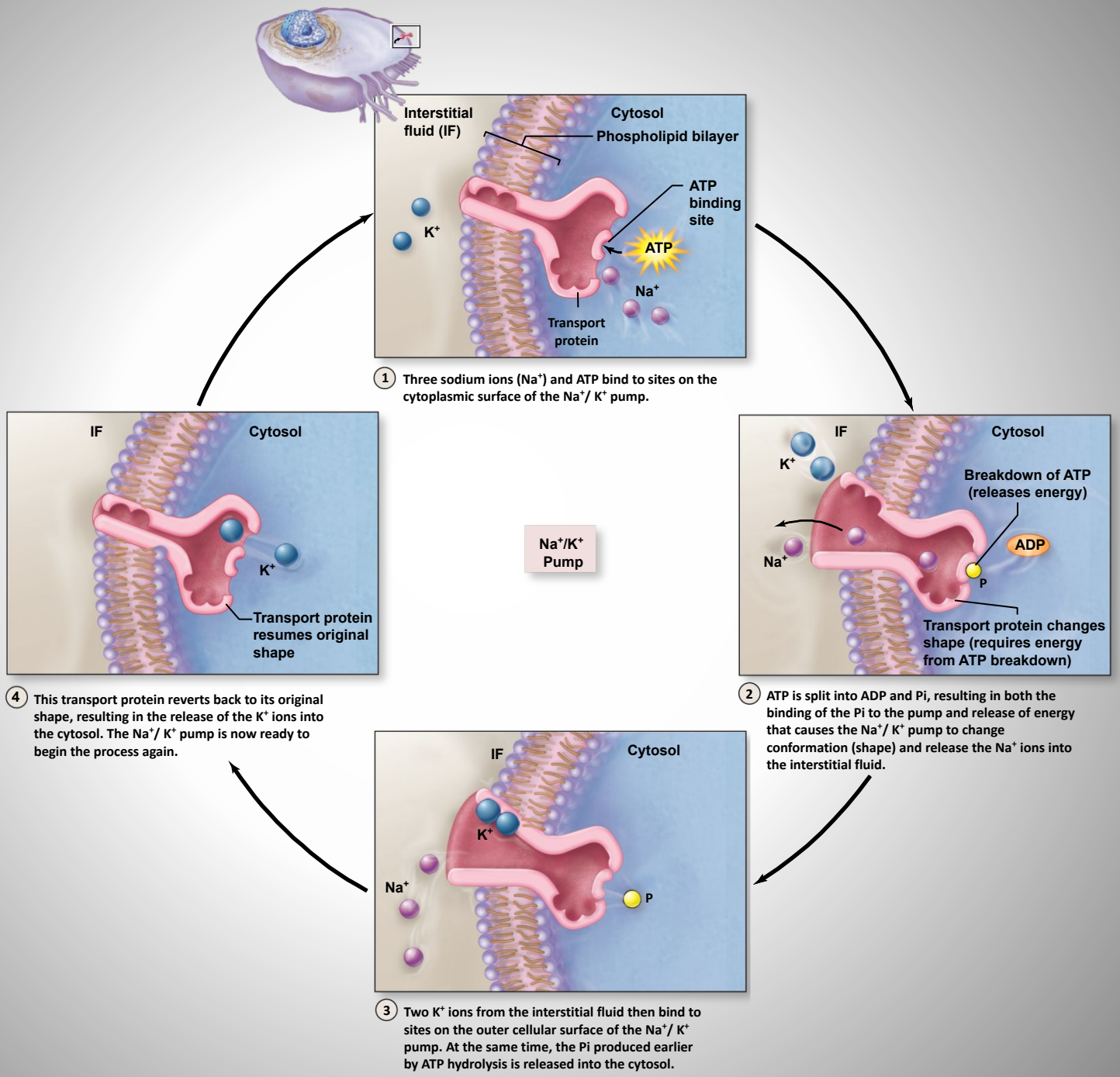
- Sodium-potassium pump
  - Special kind of ion pump, an *exchange* pump
  - Moves one ion into cell against gradient
  - Moves another ion out of cell against gradient
  - Three Na^+ pumped out for two K^+ pumped in
  - Maintains steep membrane gradient
  - Requires ATP

Membrane Transport: Active Processes

Active Transport

- Sodium-potassium pump *(continued)*
  - Maintains an **electrochemical gradient**
    - electrical charge difference across plasma membrane
    - due to unequal distribution of positive and negative substances across membrane
    - voltage differences termed **membrane potential**
    - at rest, termed **resting membrane potential**

Figure 4.14



Membrane Transport: Active Processes

Active Transport *(continued)*

- **Secondary active transport**
  - Moves substance against concentration gradient
  - Uses energy provided by movement of second substance down gradient
  - Kinetic energy providing “power” to pump other substance
  - Na^+ moving down concentration gradient
  - Ultimately dependent on Na^+/K^+ pumps for energy

Membrane Transport: Active Processes

Active Transport

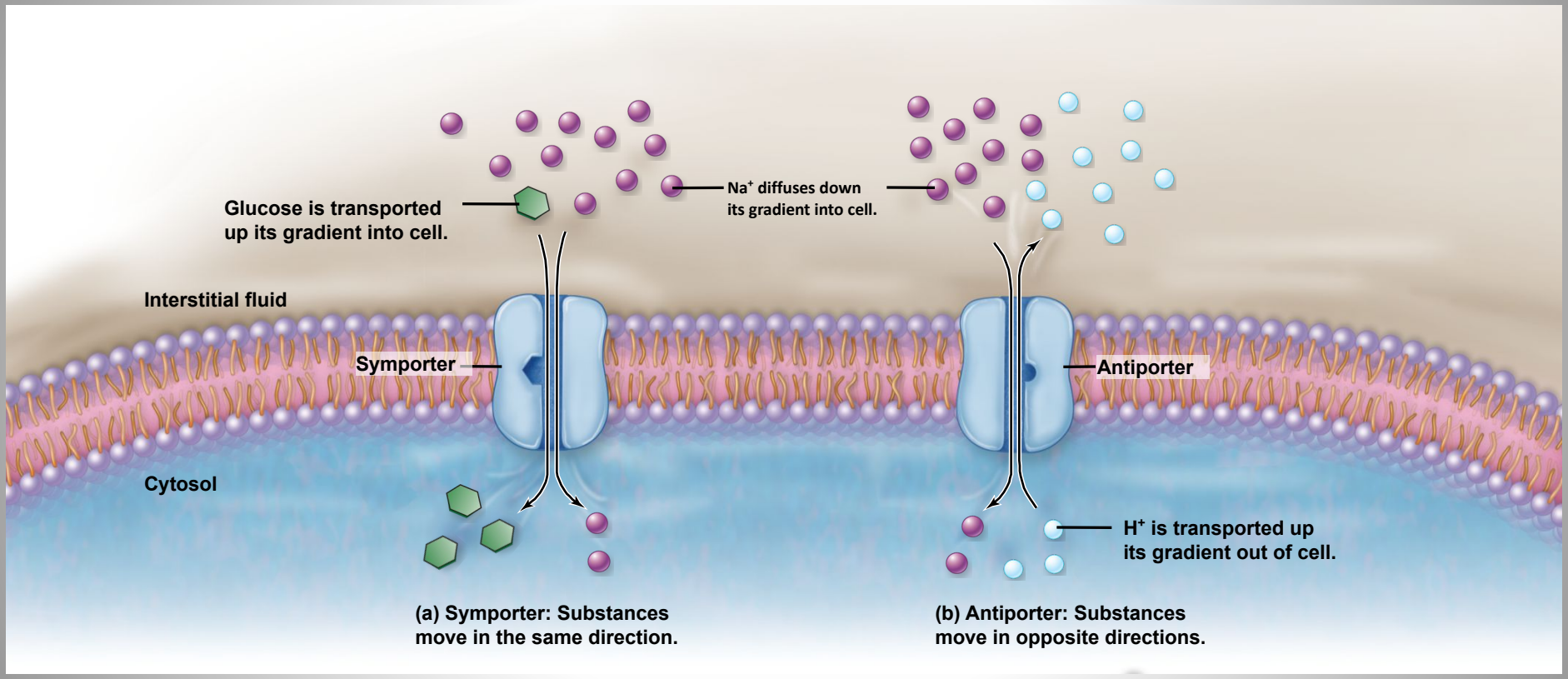
- **Secondary active transport** *(continued)*
  - Two substances moved in same direction
    - proteins termed **symporters**
    - process **symport secondary active transport**
    - e.g., glucose transported up its gradient into cell
      - Na^+ and glucose moved in same direction

Membrane Transport: Active Processes

Active Transport

- **Secondary active transport** *(continued)*
  - Two substances moved in opposite directions
    - proteins termed **antiporters**
    - process termed **antiport secondary active transport**
    - e.g., H^+ transported up its gradient out of cell
      - Na^+ and H^+ moved in opposite directions

Figure 4.15



Membrane Transport: Active Processes

Vesicular Transport

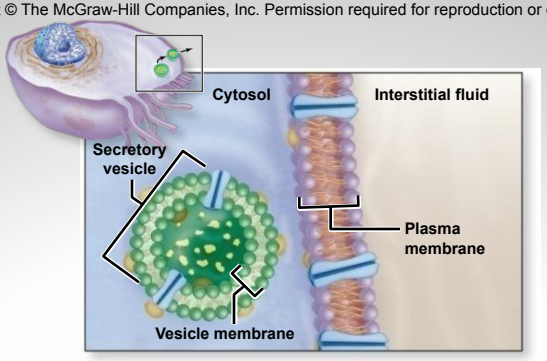
- Requires **vesicles**
  - membrane-bounded sac filled with materials
- Requires energy to transport vesicles
- Exocytosis
  - vesicle fuses with membrane
  - releases substances outside the cell
- Endocytosis
  - vesicle encloses material outside cell
  - fuses with membrane to release inside cell

Membrane Transport: Active Processes

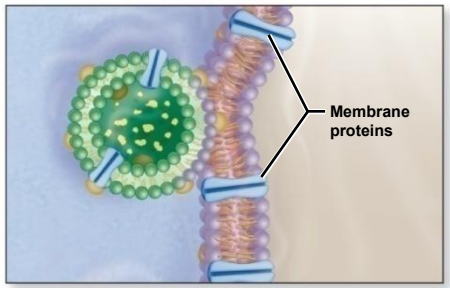
Vesicular Transport *(continued)*

- **Exocytosis**
  - How large substances are secreted from cell
  - Macromolecules too large to be moved across membrane
  - Material packed within intracellular transport vehicles
  - Vesicle and plasma membrane fusion
    - requires ATP
  - Contents released to outside of cell
  - E.g., release of neurotransmitters from nerve cells

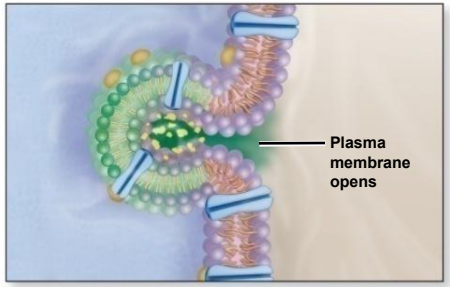
Figure 4.16



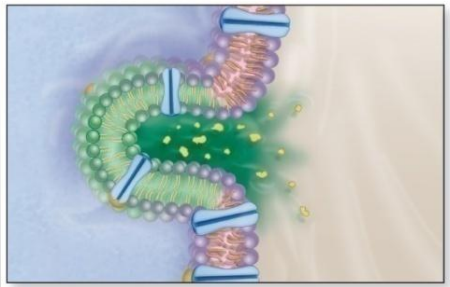
1 Vesicle nears plasma membrane



2 Fusion of vesicle membrane with plasma membrane



3 Plasma membrane opens to outside of cell



4 Release of vesicle components into the interstitial fluid and integration of vesicle membrane components into the plasma membrane

Membrane Transport: Active Processes

Vesicular Transport *(continued)*

- **Endocytosis**
  - Cellular uptake of large substances from external environment
  - Used for the uptake of materials for digestion
  - Used for retrieval of membrane from exocytosis
  - Used for regulating membrane protein composition
    - to alter cellular processes
  - Three types:
    - phagocytosis, pinocytosis, and receptor-mediated endocytosis

Membrane Transport: Active Processes

Vesicular Transport *(continued)*

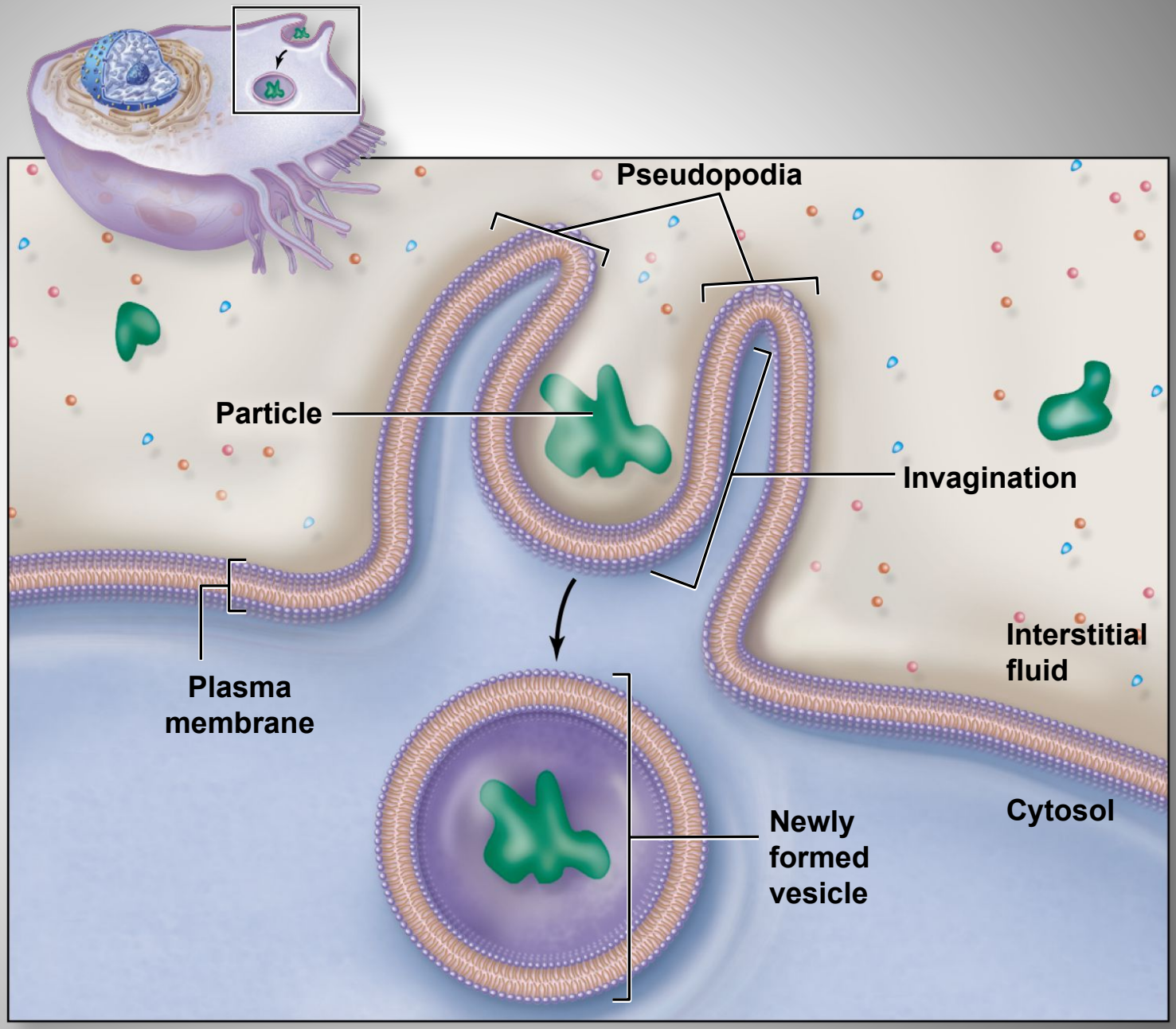
- Steps of endocytosis
  - Substances within interstitial fluid packaged into a vesicle
  - Vesicle formed at cell surface
  - Inward fold of membrane to form pocket
    - termed **invagination**
  - Deepens and pinches off when layer fuses
    - requires energy
  - Intracellular vesicle with material formerly outside cell

Membrane Transport: Active Processes

Vesicular Transport *(continued)*

- **Phagocytosis**
  - Occurs when cell engulfs large particle external to cell
  - Forms large extensions termed **pseudopodia**
  - Surround particle, enclosing it in membrane sac
  - Fuses with lysosome
    - contents digested here
  - Only in a few cell types
    - E.g., white blood cells engulfing microbes

Figure 4.17a



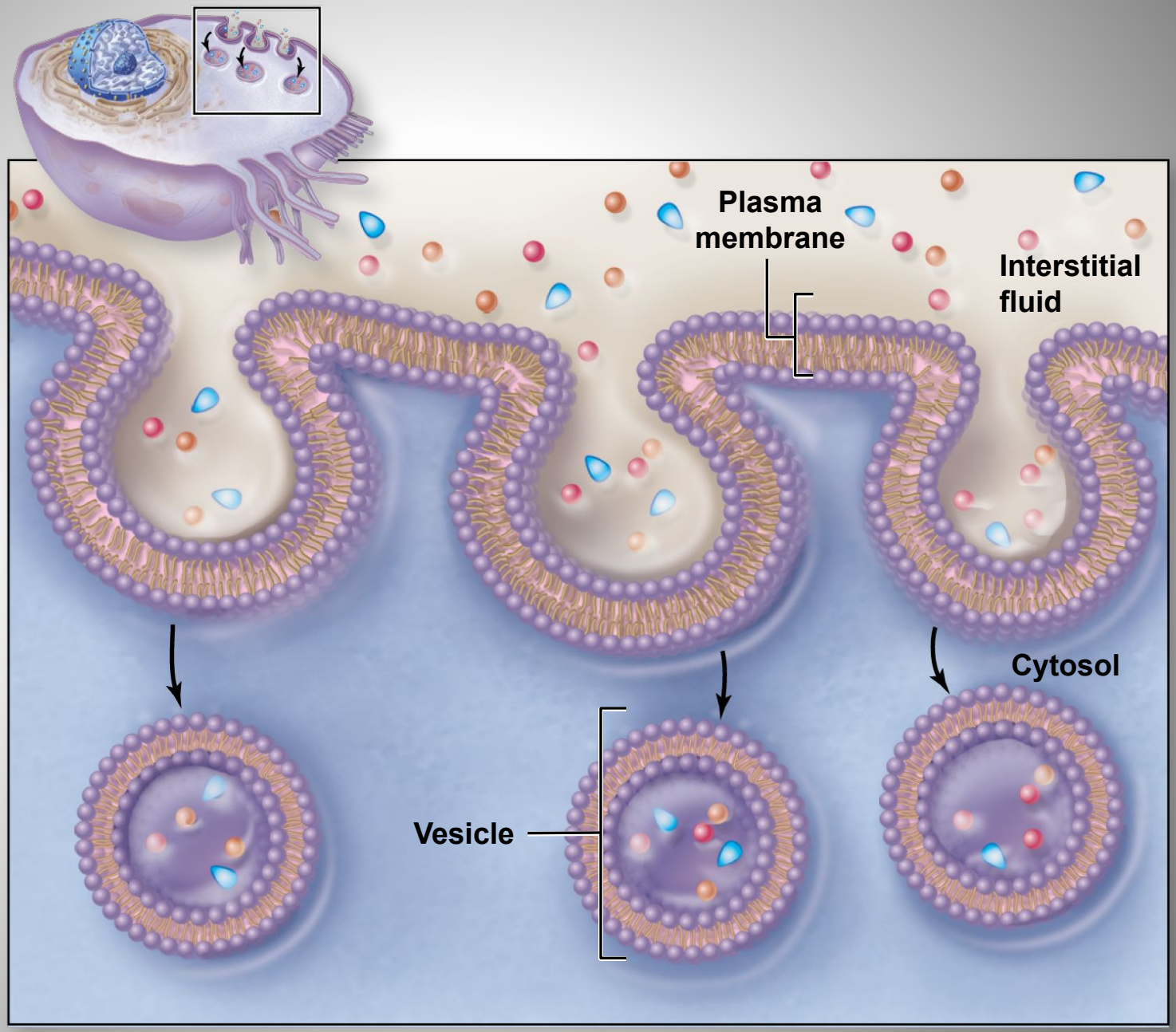
(a) Phagocytosis

Membrane Transport: Active Processes

Vesicular Transport *(continued)*

- **Pinocytosis**
  - Internalization of droplets of interstitial fluid
  - Multiple, small vesicles formed
  - All dissolved solutes taken into cell
  - Performed by most cells
  - E.g., cells of capillary wall

Figure 4.17b



(b) Pinocytosis

Membrane Transport: Active Processes

Vesicular Transport *(continued)*

- **Receptor-mediated endocytosis**
  - Movement of specific molecules from interstitial environment into a cell
  - Requires binding to a receptor
  - Enables cell to obtain bulk quantities of substances
  - E.g., transport of cholesterol from blood to a cell
    - cholesterol in blood in structures termed low-density lipoproteins
    - LDLs internalized by this process

Membrane Transport: Active Processes

Vesicular Transport *(continued)*

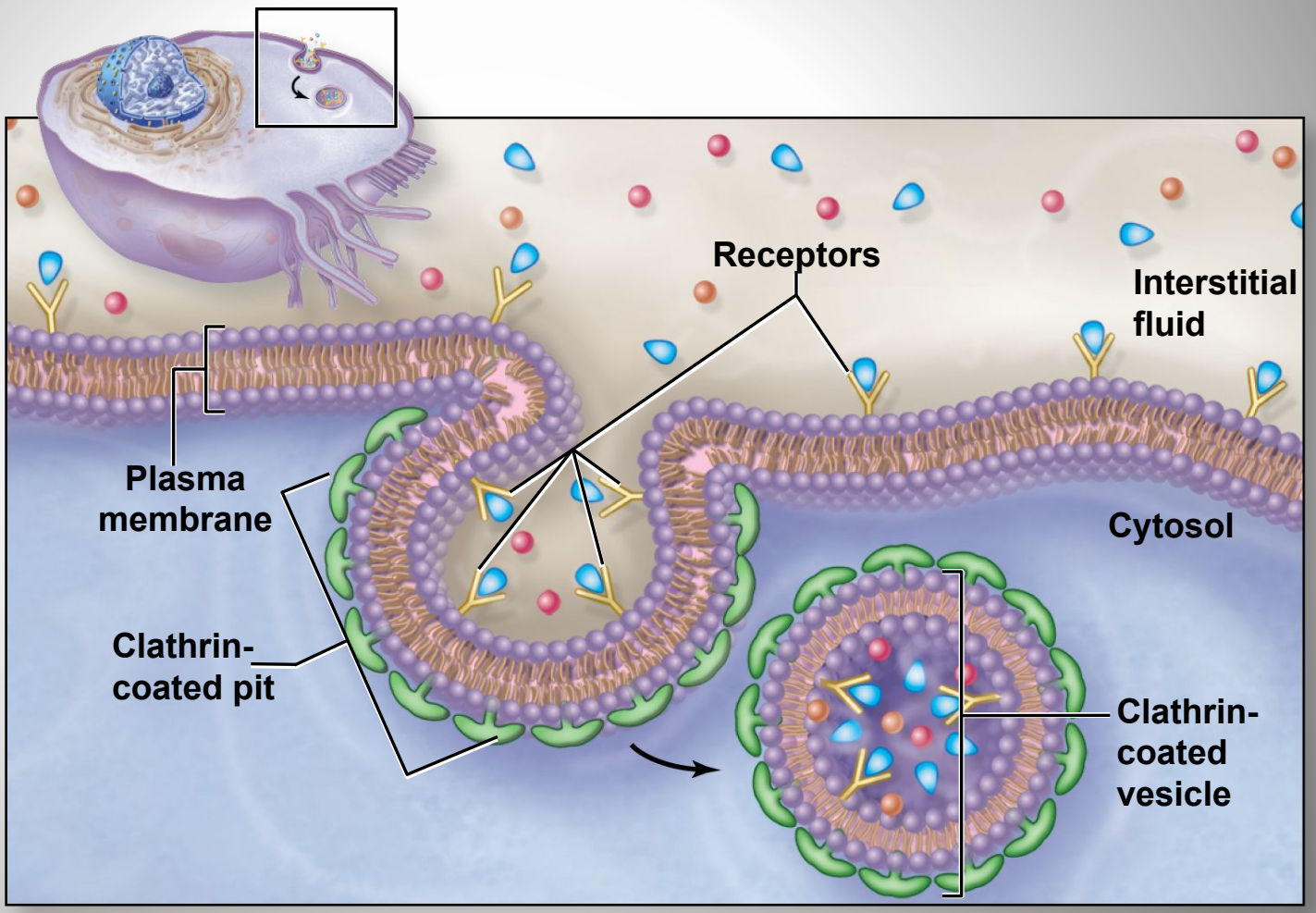
- Steps of receptor-mediated endocytosis
  - Molecule binding to protein receptors in membrane
  - Form ligand-receptor complex
  - Accumulate at special regions containing **clathrin** protein
  - Fold inward to form clathrin-coated pit
  - Form clathrin-coated vesicle
  - Moves into cytosol
  - Fusion of lipid bilayers requiring ATP

Membrane Transport: Active Processes

Vesicular Transport *(continued)*

- Steps of receptor-mediated endocytosis
  - Molecule binding to protein receptors in membrane
  - Form ligand-receptor complex
  - Accumulate at special regions containing **clathrin** protein
  - Fold inward to form clathrin-coated pit
  - Form clathrin-coated vesicle
  - Moves into cytosol
  - Fusion of lipid bilayers requiring ATP

Figure 4.17c



(c) Receptor-mediated endocytosis

Figure 4.18a

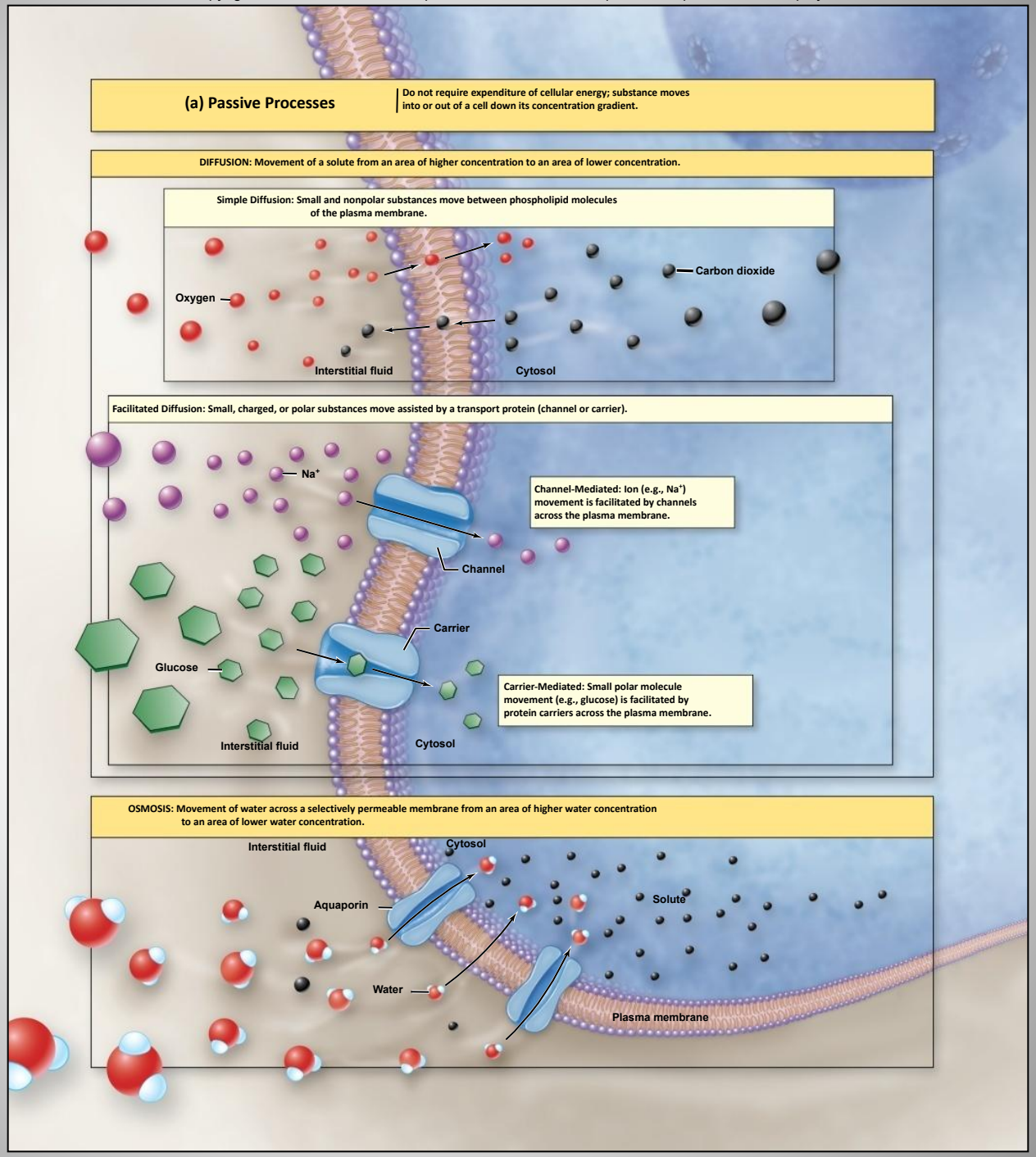
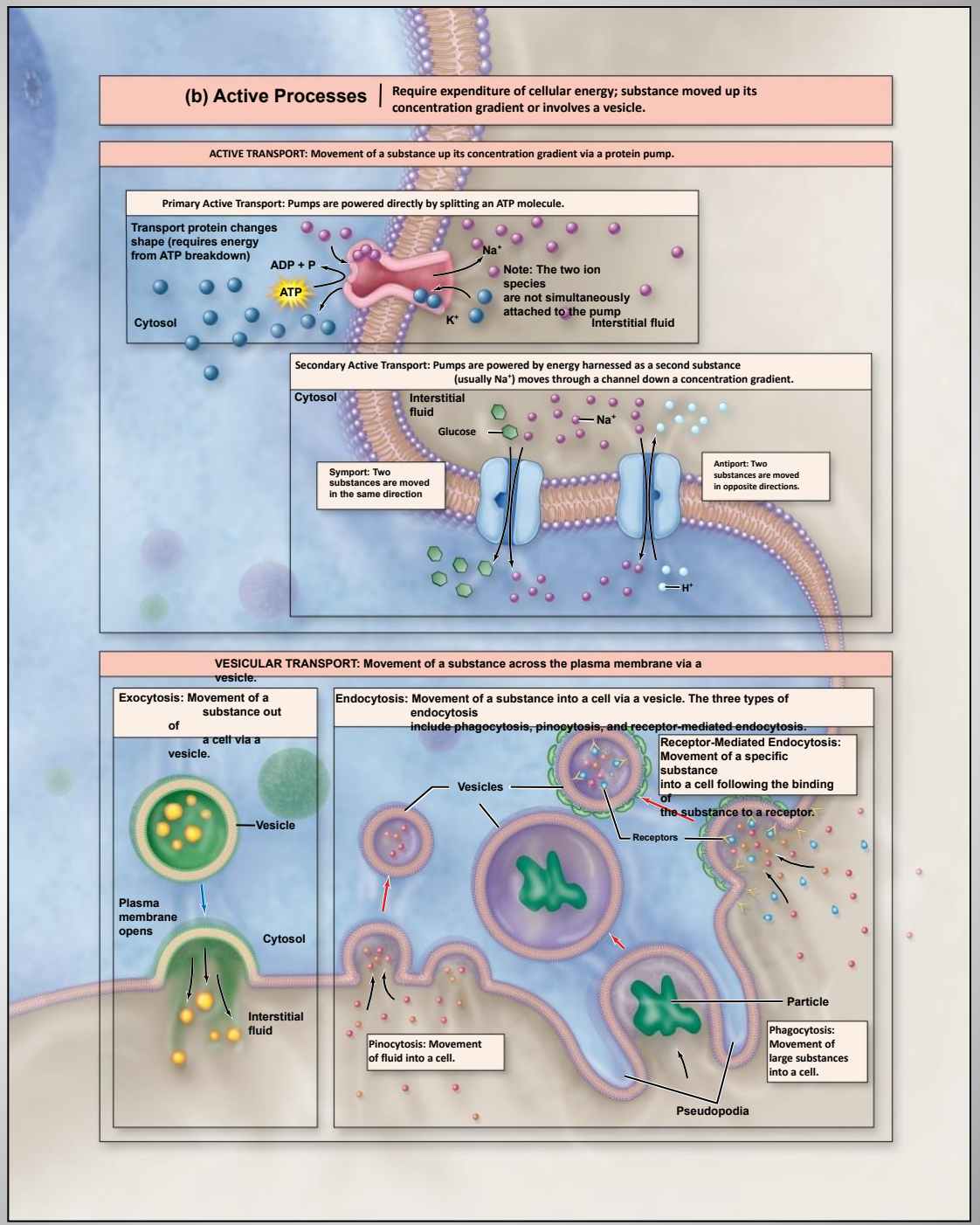


Figure 4.18b



Membrane Transport: Active Processes

Clinical View: Familial Hypercholesteremia

- Inherited genetic disorder
- Defects in LDL receptor or proteins of LDLs
- Interfere with normal receptor-mediated endocytosis of cholesterol
- Results in greatly elevated cholesterol
- Causes atherosclerosis
- Greatly increased risk of heart attack